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Feasibility of Recirculating Bottom Ash Transport Water in Coal-Fuelled Power Generating Stations

Economic and Technical Review
Report EPS 3-WP-83-1

Water Pollution Control Directorate
February 1983

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FEASIBILITY OF RECIRCULATING BOTTOM ASH TRANSPORT WATER IN COAL-FUELLED POWER GENERATING STATIONS

by

Dearborn Environmental Consulting Services

for the

Water Pollution Control Directorate
Environmental Protection Service
Environment Canada

Report No. EPS 3-WP-83-1
February 1983

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ERRATA

Report EPS 3-WP-83-1 — Feasibility of Recirculating Bottom Ash Transport Water in Coal-Fuelled Power Generating Stations

p. 104, Table 27 - On right side of table, under "Water Stream"

"T.D." should read "W.D."
"OLN" should read "Cleaning"
"PPO" should read "protection"

p. 105, Table 28 - Under "Waste Stream",

"Flash back drain" should read "Flash tank drain"
"I.D. for blowing cooling water" should read "I.D. for fan bearing cooling water"

p. 132, Section 5.2.7 - At end of definition of "Ci_4", insert "(used to calculate K_i)"

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ABSTRACT

This study examines the technical feasibility of recirculating the water used to transport bottom ash in coal-fired steam electric generating stations. Information for this examination was gathered from the literature, from generating stations, and from manufacturers of ash handling systems.

Successful design and operation of completely recirculating water systems for bottom ash transport must take into account both hydraulic and chemical considerations. To prevent discharge of ash sluice water for hydraulic reasons, there must be no continuing net accumulation of water in the ash system. The total water inputs from in-plant wastes, precipitation, runoff, and fresh water used around the bottom ash system must be balanced by water losses due to occlusion with the bottom ash, evaporation and re-use of excess transport water for other plant services. Hydraulically, zero discharge from recirculating bottom ash transport systems can be achieved by limiting makeup water to the one to two percent normal water loss from the system.

The chemical characteristics of the bottom ash transport water are related to intake water quality, method of coal combustion, and the chemical properties of the bottom ash. It has been suggested that wastewater blowdown from a recirculating system may be required to control the gradual accumulation of scale-forming minerals in the ash sluice water. Simple theoretical water chemistry suggests that scaling in the system could occur after a limited number of cycles. In many systems calcium carbonate would be the most likely scale-forming substance to accumulate in the transport system. In actual operating systems the abrasive nature of the bottom ash slurry tends to erode scale which begins to accumulate on the sluice side of the recycle system. In certain very specific situations the scaling potential may become severe enough to require blowdown. In these cases, methods such as sidestream lime soda softening and acid cleaning can be used to eliminate the accumulation of scale. The chemical characteristics of the ash water do not therefore present an obstacle to complete recirculation except in special circumstances.

RÉSUMÉ

Basée sur l'information obtenue des centrales électriques, chez des fabricants de systèmes de manutention des cendres, et dans la documentation, l'étude examine s'il est possible de recirculer l'eau utilisée pour évacuer les cendres du cendrier des chaudières génératrices de vapeur dans les centrales à charbon.

Le calcul et l'exploitation d'un système de recirculation intégrale de l'eau doit tenir compte de considérations à la fois hydrauliques et chimiques. Afin d'empêcher le rejet de l'eau de conduit d'évacuation des cendres pour des raisons hydrauliques, il ne doit pas y avoir accumulation nette constante de l'eau. L'apport total des eaux usées de la centrale, des précipitations, du ruissellement et d'eau fraîche utilisée près du système d'évacuation doit être compensé par les pertes dues à l'occlusion par les cendres, à l'évaporation et à la réutilisation de l'eau excédentaire d'évacuation, ailleurs dans la centrale. Du point de vue hydraulique, le rejet d'eau d'évacuation peut être nul si on limite le volume d'eau d'appoint à 1 ou 2 % des pertes normales d'eau du système.

Les caractéristiques chimiques de l'eau d'évacuation des cendres sont reliées à la qualité de l'eau de prise, à la méthode de combustion du charbon et aux propriétés chimiques des cendres. Il a été proposé de purger l'eau pour empêcher l'accumulation graduelle, dans l'eau d'évacuation, de minéraux susceptibles de former du tartre. D'après des notions théoriques simples de la chimie de l'eau, il pourrait y avoir entartrage après un nombre restreint de cycles. Dans un grand nombre de systèmes, le carbonate de calcium serait la substance entartrante la plus susceptible de s'accumuler. Dans les systèmes actuels, la nature abrasive de la suspension de cendres tend à éroder le tartre qui commence à s'accumuler sur les parois du conduit de recirculation. Dans certains cas très particuliers, la possibilité d'entartrage peut devenir assez forte pour exiger une purge. On peut alors utiliser des méthodes comme l'adoucissement à la chaux et à la soude et le nettoyage à l'acide en circulation latérale pour éliminer le tartre. Les caractéristiques chimiques de l'eau d'évacuation ne constituent donc pas un obstacle à sa recirculation intégrale, sauf dans des circonstances spéciales.

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1.0 INTRODUCTION

In Canada, coal-fired generating stations represent about 38 percent of the total steam electric generating capacity (1). In 1978, 2.24×10^7 tonnes of coal were burned. Based on current estimates, 5.81×10^7 tonnes of coal will be used in 1989 (2). Coal-fired plants currently produce 8.31×10^5 tonnes of bottom ash each year, at an average annual rate of about 57 tonnes per megawatt of generating capacity (2).

Bottom ash has traditionally been transported hydraulically in sluice systems and disposed of in ash ponds. The transport water, after separation of the suspended particulate matter, contains residual concentrations of a wide variety of chemical contaminants including various heavy metals and, possibly, complex organic compounds. As a result, the discharge of bottom ash sluice water from conventional once-through systems may be environmentally hazardous if these contaminants are not removed.

Because untreated bottom ash transport waters are of environmental concern and treatment of large volumes of wastewater can be costly, it may be advantageous to employ a closed system for the continuous recycle or reuse of this service water stream. Ideally such a system should operate with no direct discharge of contaminated water to the environment. Although systems with a high degree of recycle are now in operation, apprehension still exists about the possible operational and water chemistry problems associated with the complete closing of bottom ash sluicing systems. Consequently, an evaluation of the potential problems, design requirements and appropriate operating procedures of recirculating bottom ash water systems under Canadian conditions is required.

1.1 Objectives

The main objective of this study was to assess the feasibility of completely closed systems for bottom ash transport water in coal-fuelled, steam electric generating stations in Canada.

Specific tasks of the study were:

- to review the technical literature describing the design and operation of bottom ash water recirculating systems;
- to visit generating stations that employ recycle systems for bottom ash transport water and to report on the operating characteristics of these systems.

- to determine the factors that affect the blowdown requirements in such systems and to review the means available to reduce blowdown to minimum levels or to eliminate it entirely.
- to evaluate site-specific Canadian circumstances which could affect the operation of bottom ash recirculating systems.

1.2 Contents of this Report

This report is divided into seven major sections. Following the introduction, Section 2 describes the factors affecting coal ash properties and the quantities of coal ash produced in Canada. The characteristics of coal ash and the effects of these on recirculating ash water systems are also presented.

Section 3 describes once-through and recirculating bottom ash transport water systems, including details on the major components in these systems, and introduces possible problems with recirculating systems.

Reports on the operation of 12 existing bottom ash transport systems are presented in Section 4. Each case history includes details on the bottom ash transport water balance, possible scaling problems, and other operational problems encountered.

In Section 5 the factors affecting recirculation and reuse of bottom ash transport waters are described. The major areas addressed are the hydraulic balance of the system, accumulation of chemical constituents and scaling problems, and other site-specific problems.

Options for the treatment or re-use of blowdown from recirculating bottom ash transport water systems are briefly described in Section 6. The available options presented include cascade water use, sidestream treatment and effluent treatment.

The feasibility of operating completely closed bottom ash transport water systems is discussed in Section 7. The summary and conclusions of this study are presented in this section.

2.0 ASH GENERATION AND CHARACTERISTICS IN COAL-FIRED STEAM ELECTRIC GENERATING STATIONS

The major operations of a coal-fired steam electric generating station are shown schematically in Figure 1. Coal is metered, ground by large pulverizers and blown into the boiler where it is burned. The heat is used to produce steam to drive turbine generators.

During combustion, two types of ash are produced. Fly ash is the light particulate matter which is carried up out of the boiler in the flue gas and removed from the stack gases by air pollution control equipment such as electrostatic precipitators, bag filters and scrubbers. Bottom ash is the combination of heavier ash particulate matter and molten slag which descends and collects in the boiler bottom.

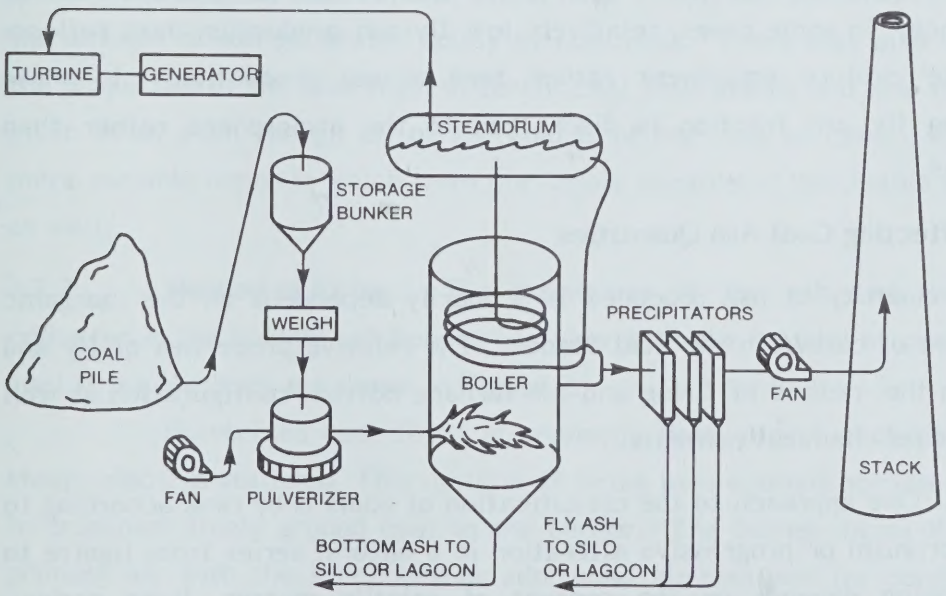


FIGURE 1 TYPICAL THERMAL GENERATION SYSTEM ASH PRODUCTION (3)

2.1 Quantities of Ash Generated by Canadian Power Utilities

2.1.1 Bottom Ash. A recent study of the potential uses of ash from fossil-fired generating stations indicates that the total production of bottom ash from Canadian coal-fired stations in 1978 was 8.31×10^5 tonnes, equivalent to approximately 59.5 tonnes of bottom ash per megawatt of generating capacity per year (2).

Based on a 1977 inventory of Canadian steam-electric generating stations (1), the rate of bottom ash production varied from about 5.4 tonnes per megawatt capacity per year to 254 tonnes per megawatt capacity per year. This extremely wide range in ash production results from differences in the ash contents of the coals burned and the fractions of the total ash collected as fly ash and as bottom ash in specific stations and the operation of the different stations. The factors influencing the quantities of ash produced are discussed in Section 2.2.

2.1.2 Fly Ash. The total fly ash produced by coal-fired generating stations in Canada in 1978 was approximately 1.79×10^6 tonnes. This is equivalent to 127.9 tonnes of fly ash per megawatt of generating capacity per year (2).

In 1977, reported fly ash production ranged from approximately 3.6 tonnes to 860 tonnes per megawatt per year (1). The same factors that influence the rate of generation of bottom ash also affect fly ash generation. However, in the case of fly ash production data, the efficiency of stack gas particulate control equipment is of considerable importance. In some cases, relatively low fly ash production data reflects inefficient particulate capture equipment rather than actual production. In these instances, the missing fly ash fraction is discharged to the atmosphere rather than captured and measured.

2.2 Factors Affecting Coal Ash Quantities

The total quantity of ash produced is primarily dependent on the inorganic content and the amount of carbon in the coal burned. The relative properties of fly and bottom ash depend on the method of firing and the furnace bottom configuration as well as on the coal type and its chemical contents.

2.2.1 Coal Type. One approach to the classification of coals is by rank according to the degree of metamorphism or progressive alteration in a natural series from lignite to anthracite. The ranking depends on the content of volatile matter, fixed carbon, moisture, and oxygen but no single factor completely defines the coal.

Anthracite coal has the highest percentage of fixed carbon and the lowest percentage of volatile matter. Bituminous coal is a lower rank of coal than anthracite and has a lower percentage of fixed carbon and a higher percentage of volatile matter. Sub-bituminous coal is a lower rank of coal occurring in western North America while lignite coals rank below sub-bituminous coals. Generally, bituminous, sub-bituminous and

lignite coals are used for power generation. In Eastern Canada, steam electric utilities have normally used bituminous coals for steam generation while in Western Canada local sub-bituminous and lignite rank coals have been widely used. As a result, the bottom ashes produced in these two regions are distinctly different.

The wide variation in the ash contents of different coals is shown below (4):

Coal Rank	Range of Ash Content (%)
Anthracite	4 - 19
Bituminous	3 - 32
Sub-Bituminous	3 - 16
Lignite	4 - 19

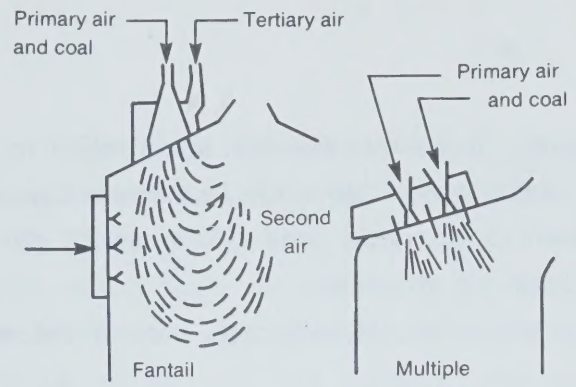
Because of these wide ranges in ash content and, in some cases, the use of high grade metallurgical coal rejects which have a high ash content, it is difficult to predict the amount of ash generated solely by coal rank. There may also be large differences in the properties of the coal from different coal field seams and also different locations in a given seam even though all of the coal is of one rank or class. Higher ash content and more variable deposits which were previously considered unsuitable are now being utilized as well.

2.2.2 Method of Firing. The properties of the ash and the portion of the ash collected in the bottom ash hopper can vary with the method of coal firing. The common coal firing methods are shown in Figure 2.

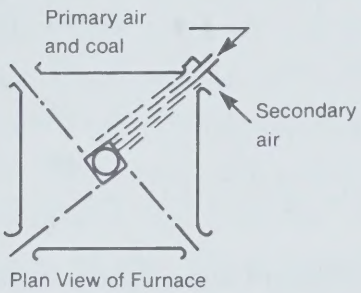
Pulverized coal firing is presently used almost exclusively in large Canadian steam electric stations. This method of firing uses a small portion of the combustion air to transport finely ground coal to the burner. The burner mixes the pulverized coal and primary air with the secondary or additional air required for combustion. This method produces large amounts of fly ash relative to bottom ash.

Cyclone-fired furnaces are not commonly used by utilities in Canada. In this type of furnace, initial combustion occurs in a primary furnace. The gases produced then flow into the main furnace where the rest of the combustion process occurs. This method of firing produces less fly ash and more bottom ash than pulverized firing methods.

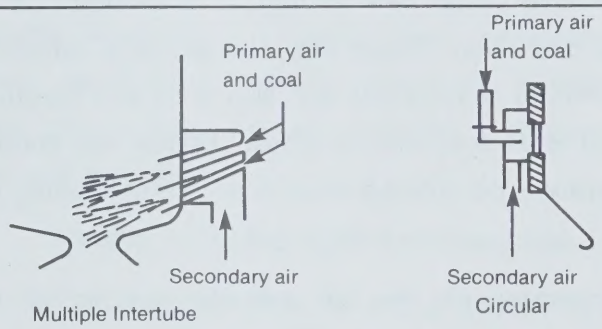
A comparison of the distribution of bottom and fly ash by method of firing is shown in Table 1. Typically, in pulverized coal firing 65 to 85 percent of the coal ash is



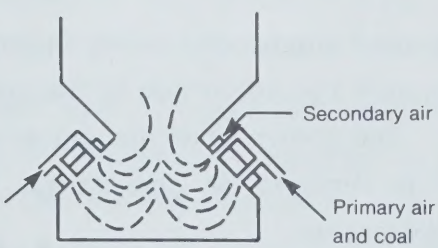
Pulverized vertical firing



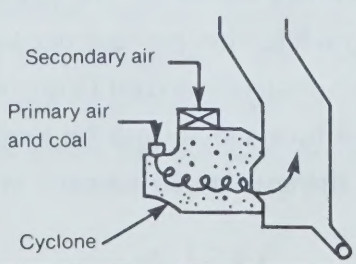
Pulverized tangential firing



Pulverized horizontal firing



Pulverized opposed inclined firing



Cyclone firing

FIGURE 2 METHODS OF COAL FIRING (5)

entrained in the flue gas as fly ash and about 15 to 35 percent is retained as bottom ash. In cyclone-fired furnaces as much as 90 percent of the total ash may be produced as bottom ash with as little as 10 percent produced as fly ash.

TABLE 1 COMPARISON OF DISTRIBUTION BETWEEN BOTTOM ASH AND FLY ASH BY METHOD OF FIRING (6)

Type of Firing	Percent Bottom Ash (typical)	Percent Fly Ash (typical)
Pulverized coal front firing	15 - 35	65 - 85
Pulverized coal opposed firing	15 - 35	65 - 85
Pulverized coal tangential firing	15 - 35	65 - 85
Cyclone	90	10
Cyclone (7)	70 - 80	20 - 30

2.2.3 Furnace Bottom Configuration. "Dry bottom" furnaces are used for burning pulverized coals with high ash fusion temperatures. In these systems large boiler bottoms with sufficient cooling are used so the impinged ash on the furnace walls is solid and dry and can be removed as dry particules. These particles are smaller and more uniform in size than slag tap or "wet bottom" furnace ash.

Slag tap or wet bottom furnaces are used for coals with low ash fusion temperatures. Liquid slag is collected on the furnace floor and is tipped into a slag tank containing water. The bottom ash particles are larger and less uniform in size. As indicated previously, this type of furnace produces a large proportion of bottom ash (8). Wet bottom furnaces are not commonly used by utilities in Canada.

The effect of the type of furnace bottom on the portion of bottom and fly ash for pulverized fired coal is shown below (6):

Furnace Bottom	Percent Bottom Ash	Percent Fly Ash
Wet	35	65
Dry	15	85

2.3 Factors Affecting Coal Ash Chemical Properties

The chemical properties of the coal ash influence the water chemistry in hydraulic ash transport systems. The major components of coal ash from combustion of different ranks of coal are shown in Table 2. Although there is a general variation in the presence of chemical species among the different coals, the chemical properties of coal ashes cannot be precisely predicted based solely on coal rank due to the wide range in concentrations of elements within each coal type and deposit.

In eastern Canada, bituminous coals which produce ash that contains more Fe_2O_3 than CaO and MgO are commonly used. In western Canada, lignite coals which produce ashes with greater concentrations of CaO and MgO than Fe_2O_3 are common. Because of these differences in the ashes, different ash collection and handling systems may be used.

Although the basic properties of a coal ash can be crudely estimated, there can be a considerable difference between the concentrations of individual elements in the fly ash and the bottom ash produced from a specific coal. This unequal distribution, or partitioning of elements, appears to result primarily from the volatilization of the coal constituents in the furnace.

The chemical elements in a coal in a particular furnace can be categorized as follows:

Group 1 - elements that are distributed equally in bottom and fly ash.
Group 2 - elements that are preferentially concentrated in the fly ash portion.
Group 3 - elements that are emitted into the atmosphere as gaseous species.

Elements with volatilization temperatures higher than those in the furnace are, generally, equally distributed between bottom and fly ash (Group 1). Some of the elements volatilized may condense on or adsorb to the fine fly ash particles and these are thus concentrated in the fly ash (Group 2). Other elements which are volatilized but do not condense are emitted from the stack (Group 3).

A variety of studies have been conducted on the partitioning of elements. The results of one study are shown in Table 3. The ash was produced from a generating station which had a peak capacity of 290 MW from each of three cyclone-fired boilers. Fly ash was collected by high-efficiency electrostatic precipitators.

TABLE 2 PERCENTAGE VALUES OF VARIATIONS IN COAL ASH COMPOSITION WITH RANK (4)

Rank	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	SO_3
Anthracite	48 - 68	24 - 44	2 - 10	1.0 - 2	0.2 - 4	0.2 - 1	-	-	0.1 - 1
Bituminous	7 - 68	4 - 39	2 - 44	0.5 - 4	0.7 - 36	0.1 - 4	0.2 - 3	0.2 - 4	0.1 - 32
Subbituminous	17 - 58	4 - 35	3 - 19	0.6 - 2	2.2 - 52	0.5 - 8	-	-	3.0 - 16
Lignite	6 - 40	4 - 26	1 - 34	0.0 - 0.8	12.4 - 52	2.8 - 14	0.2 - 28	0.1 - 1.3	8.3 - 32

TABLE 3 PARTITIONING OF ELEMENTS IN COAL ASH FROM CYCLONE BOILERS (9)

Group	Elements
I - Elements equally distributed in bottom and fly ash	aluminium, barium, calcium, cerium, cobalt, copper, iron, hafnium, potassium, rubidium, scandium, silicon, samarium, strontium, tantalium, thorium, titanium
II - Elements preferably concentrated in fly ash	arsenic, cadmium, copper, gallium, molybdenum, rubidium, antimony, sulphur, zinc
III - Elements tending to be discharged into atmosphere as vapour	mercury, chlorine, bromine

Another study on the partitioning of trace elements (10) was conducted on the ash at a pulverized coal fired plant. Measurements of 17 elements indicated that aluminum, iron, rubidium, strontium, yttrium and niobium were present in constant concentrations in both ashes. Concentrations of copper, zinc, arsenic, molybdenum, antimony, lead, and selenium were generally lowest in bottom ash, and increased progressively in ash samples collected further downstream from the combustion zone.

The degree of volatilization depends on the furnace temperature which is, in turn, influenced by the coal type and firing method. The adsorption of volatilized elements on the fly ash is dependent on the surface area and surface properties of the fly ash and on the temperature profile in the furnace. For these reasons, the characteristics of the bottom and fly ashes are strongly dependent on the furnace design, coal type and firing method. These factors must be considered when examining the data reported in the literature.

2.4 Chemical Characteristics of Ash

2.4.1 Bottom Ash. The chemical constituents of bottom ash have been studied in detail (11,12). The major chemical constituents of bottom ash from southern Pennsylvanian coal are shown in Table 4 (13). The most abundant chemical compounds are oxides of silica, aluminum and iron.

TABLE 4 MAJOR CHEMICAL CONSTITUENTS OF BOTTOM ASH FROM THE SOUTHWESTERN PENNSYLVANIA REGION (13)

Constituent	Bottom Ash (% by weight)
Sulphur trioxide	0.01 - 1.0
Phosphorus pentoxide	0.01 - 0.4
Silica	19.4 - 48.9
Iron oxide	11.7 - 40.0
Aluminum oxide	18.9 - 36.2
Calcium oxide	0.01 - 4.2
Magnesium oxide	0.5 - 0.9
Sodium oxide	0.2 - 0.8
Potassium oxide	1.7 - 2.8
Titanium oxide	1.3 - 1.8

A less detailed report by Ontario Hydro (3) presented typical analyses of bottom ashes from its current operations. The results are shown in Table 5. These analytical results agree with the findings of Block and Dams (14). In the latter study, 48 Belgian coal and 20 coal ash samples were analyzed for 44 elements. Elements were classified into two groups. Oxyphilic elements in the coal ash were oxides, silicates, phosphates and carbonates. Sulphophilic elements were sulphides, selenides and antimonides.

Researchers have analyzed bottom ashes to determine the presence and concentration of trace metals of concern due to their toxic properties.

Coal from southern Illinois and western Kentucky containing 12 percent ash on a dry basis and the resultant bottom ashes were collected from cyclone-fired stations and analyzed for selected trace elements (13). The results are shown in Table 6. The pathways of 37 elements from the coal through the furnace to bottom and fly ash and flue gases were identified. Analyses were reported as elements accumulated in bottom ash, fly ash and flue gases. Bottom ash was shown to have high concentrations of aluminum, calcium, iron, potassium, magnesium and silicon.

TABLE 5 TYPICAL ANALYSES OF BOTTOM ASH (3)

Element	Bottom Ash* Content (% by weight, moisture-free)
Slicon (as SiO_2)	45.4
Aluminum (Al_2O_3)	25.6
Iron (Fe_2O_3)	13.4
Calcium (CaO)	4.6
Magnesium (MgO)	1.1
Potassium (K_2O)	1.7
Sodium (Na_2O)	1.3
Titanium (TiO_2)	**
Lead (Pb)	0.01
Zinc (Zn)	0.02
Sulphur (SO_3)	0.42
Loss on Ignition (Basically carbon)	2.0
Total Water Soluble Material	**
Soluble Sulphates	**

* Ash from pulverized coal firing of bituminous coals from Pennsylvania and West Virginia and of low-sulphur coal from western Canada.
** Not detectable.

Cox et al (15) examined coal ashes and their leaching rates for boron. The boron content of the bottom ash studied was 960 mg/kg and was not significantly leached from the bottom ash. Boron levels in fly ash were found to be as high as 1 900 mg/kg and about 50 percent was leachable into water. Other researchers (16) reported a variation in boron concentration from 17 to 120 mg/kg in bottom ash.

Andren and Klein (17) reported on the presence of selenium in coal, slag and flue gas at the Allen Steam Plant. Approximately 0.3 percent of the selenium present in the coal was incorported in the bottom ash. All of the selenium was in the elemental form.

An investigation of the liberation of mercury (18) during combustion indicated that 10 percent of the mercury released from a furnace fired with pulverized coal remained with the bottom ash. For the 700 megawatt plant studied, 330 tonnes of ash

TABLE 6 CONCENTRATIONS OF SELECTED TRACE ELEMENTS IN COAL AND BOTTOM ASH (13)

Element	Concentration (mg/L)	
	Coal*	Bottom Ash
As	4.45	18
Ba	65	500
Br	3.7	2
Cd	0.47	1.1
Ce	8.2	84
Cl	914	100
Co	2.9	20.8
Cr	18	152
Cs	1.1	7.7
Cu	8.3	20
Eu	0.1	1.1
Ga	4.5	5
Hf	0.4	4.6
Hg	0.122	0.028
La	3.8	42
Mn	33.8	295
Ni	16	85
Pb	4.9	6.2
Rb	15.5	102
Sb	0.5	0.64
Sc	2.2	20.8
Se	2.2	0.08
Sm	1.0	8.2
Sr	23	170
Ta	0.11	0.95
Th	2.1	15
U	2.18	14.9
V	28.5	260
Zn	46	100

* Mixture of coals from southern Illinois and western Kentucky. Ash content about 12 percent. Boilers were cyclone fired.

were generated per day with an average concentration of mercury of 0.2 mg/kg. This represents an elemental flow to the bottom ash of 66 g/d.

The presence of trace metals in solid and liquid wastes from coal-fired furnaces and ash transport systems has also been investigated. In one study (19), samples of pulverized coal, fly ash, bottom ash and ash pond effluent were analyzed for the presence of trace elements. The ranges of concentrations of the elements in the bottom ash samples are shown in Figure 3.

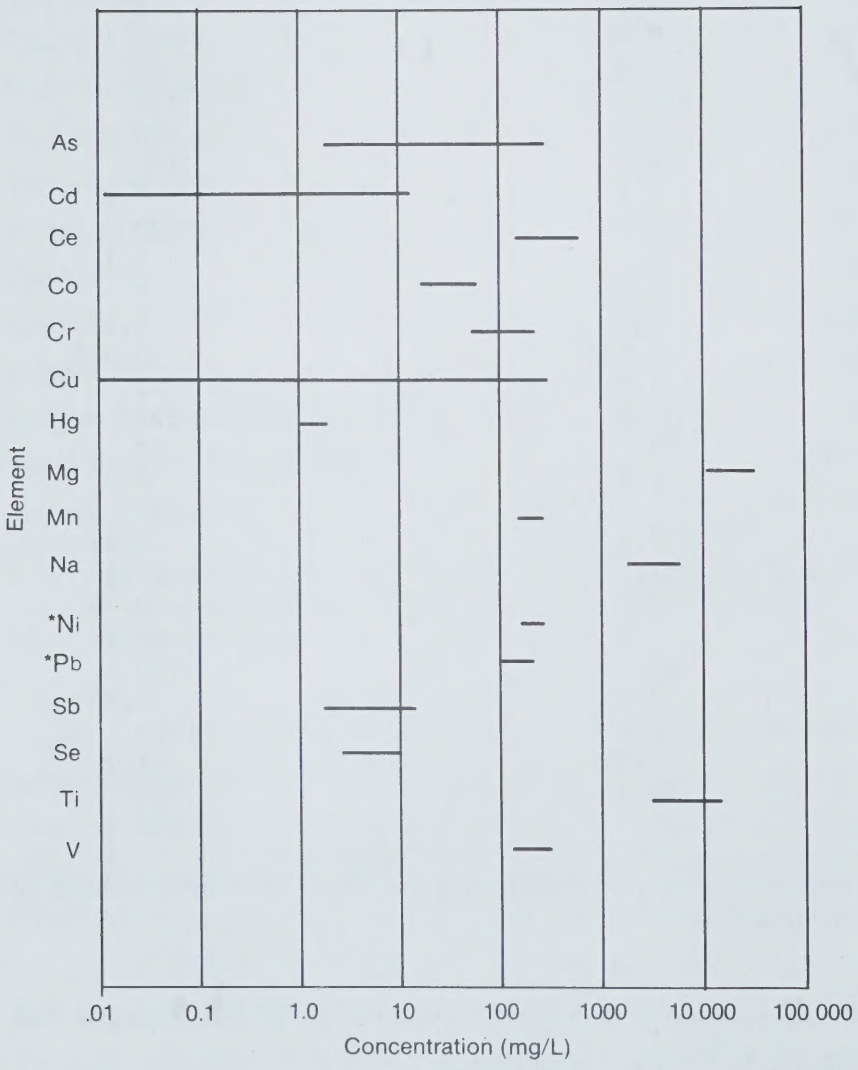


FIGURE 3 RANGE OF TRACE ELEMENTS IN BOTTOM ASH SAMPLES. ANALYSES BY NEUTRON ACTIVATION AND ATOMIC ABSORPTION* METHODS (19)
(Note: Pulverized coal fired furnace).

2.4.2 Fly Ash. Fly ash has been analyzed to determine the presence and concentrations of many chemical constituents. Table 7 presents the concentrations of the major compounds in fly ashes from the combustion of coal from southwestern Pennsylvania (13). When compared to the bottom ash produced from this coal, the fly ash contains slightly higher amounts of sulphur trioxide, calcium oxide, sodium oxide and titanium oxide.

TABLE 7 MAJOR CHEMICAL CONSTITUENTS OF FLY ASH FROM SOUTHWESTERN PENNSYLVANIA REGION COAL (13)

Constituent	Fly Ash Content (% by weight)
Sulphur trioxide	0.01 - 4.50
Phosphorus pentoxide	0.01 - 0.50
Silica	20.1 - 46.0
Iron oxide	7.6 - 32.9
Aluminum oxide	17.4 - 40.7
Calcium oxide	0.1 - 6.1
Magnesium oxide	0.4 - 1.2
Sodium oxide	0.3 - 0.8
Potassium oxide	1.2 - 2.4
Titanium oxide	1.3 - 2.0

The concentrations of many trace elements in fly ashes are significantly different than in bottom ashes.

2.5 Physical Characteristics of Ash

2.5.1 Bottom Ash. Bottom ash is primarily composed of coarser and heavier particles than fly ash and is generally angular and porous. It is usually grey to black in colour.

The physical properties of bottom ash from a generating station operated by the Tennessee Valley Authority were analyzed using column settling tests (13). Bottom ash particles ranged from 0.075 mm to greater than 2 mm in diameter. Results of the

testing are shown in Figures 4 and 5. The bottom ash settled quickly, due to its large particle size and density. After two minutes only fine particles of less than 75 μ diameter were still suspended. These represented about two percent of the total initial weight (20).

Grain size distributions for a specific bottom ash are shown in Figure 6.

Klein et al (9) reported the following bulk densities of bottom ash for four U.S. coals:

Coal Type	Bulk Density (kg/m^3)
Eastern Bituminous	720.8
North Dakota Montana Lignite	720.8
Wyoming Sub-Bituminous	720.8
Western Sub-Bituminous (other than Wyoming)	560.6 - 720.8

These analyses of the physical properties of bottom ash indicate that it can be settled quickly with only a small portion of the bottom ash not settling after only several minutes. Bottom ashes generally have bulk densities of approximately 720 kg/m^3.

2.5.2 Fly Ash. Fly ash consists of fine spherical particles ranging in diameter from 0.5 to 100 μ (21). This ash is significantly smaller in diameter than bottom ash, as indicated in Figure 6. Settling times for fly ashes are generally much greater than for bottom ash particles of equivalent density and shape. Fly ashes generally range in colour from light tan to grey or black. Increased iron content produces a tan-coloured ash (21).

Very light-weight particles, called cenospheres, may also be present in fly ash. These are silicate glass spheres which are filled with nitrogen or carbon dioxide gas and can vary from 20 μ to 200 μ in diameter. These particles can comprise as much as 20 percent by volume of the fly ash and typically have a particle density of 0.4 to 0.8 g/cc. They do not settle and instead float on top of an ash lagoon.

The specific gravity of suspended particles is the major factor governing the rate of settling. Particles of high specific gravity will settle at a faster rate than those of a specific gravity only slightly greater than that of water.

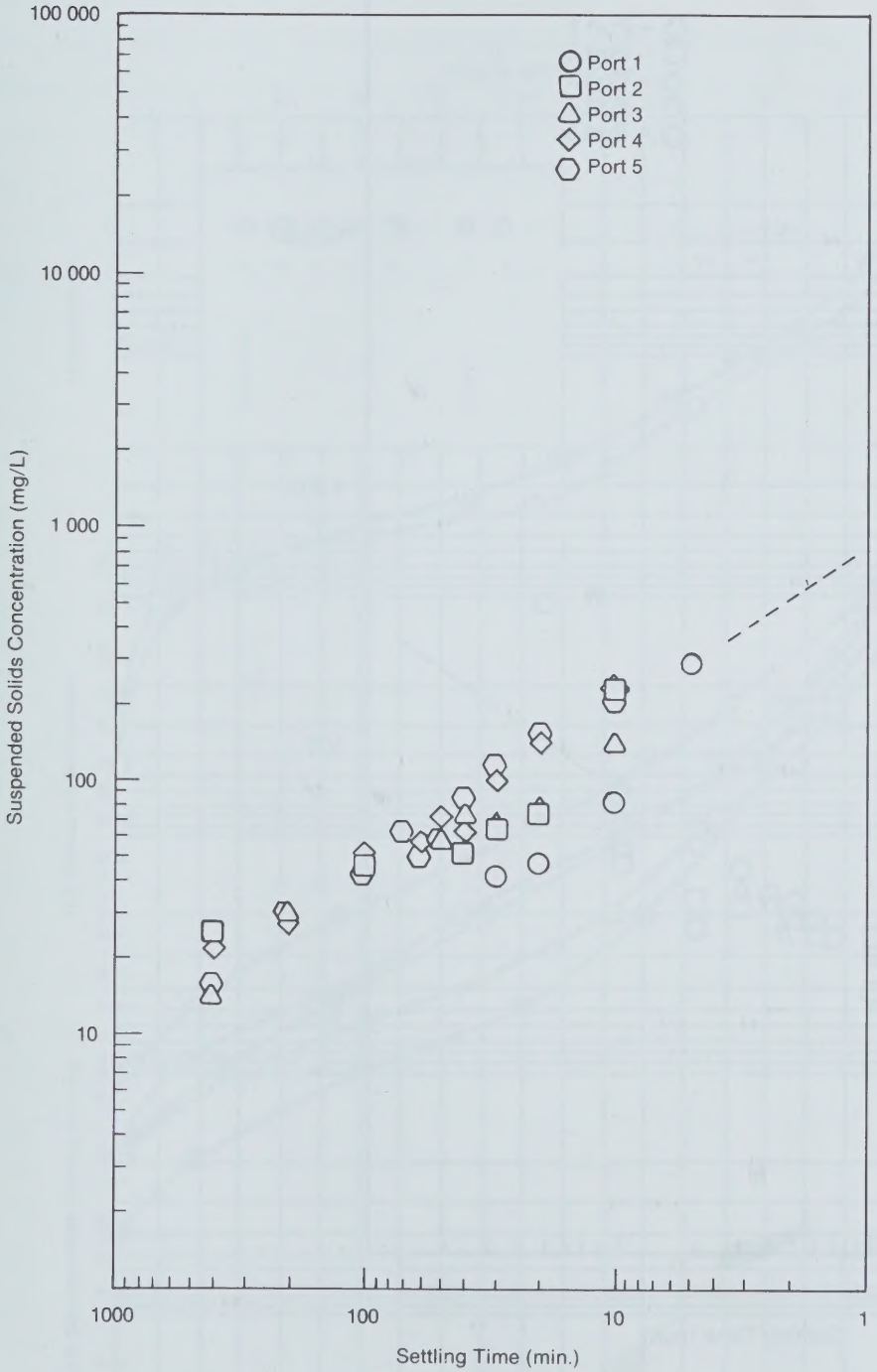


FIGURE 4 SETTLING CURVE OF BOTTOM ASH - THREE PERCENT BOTTOM ASH BY WEIGHT (13)

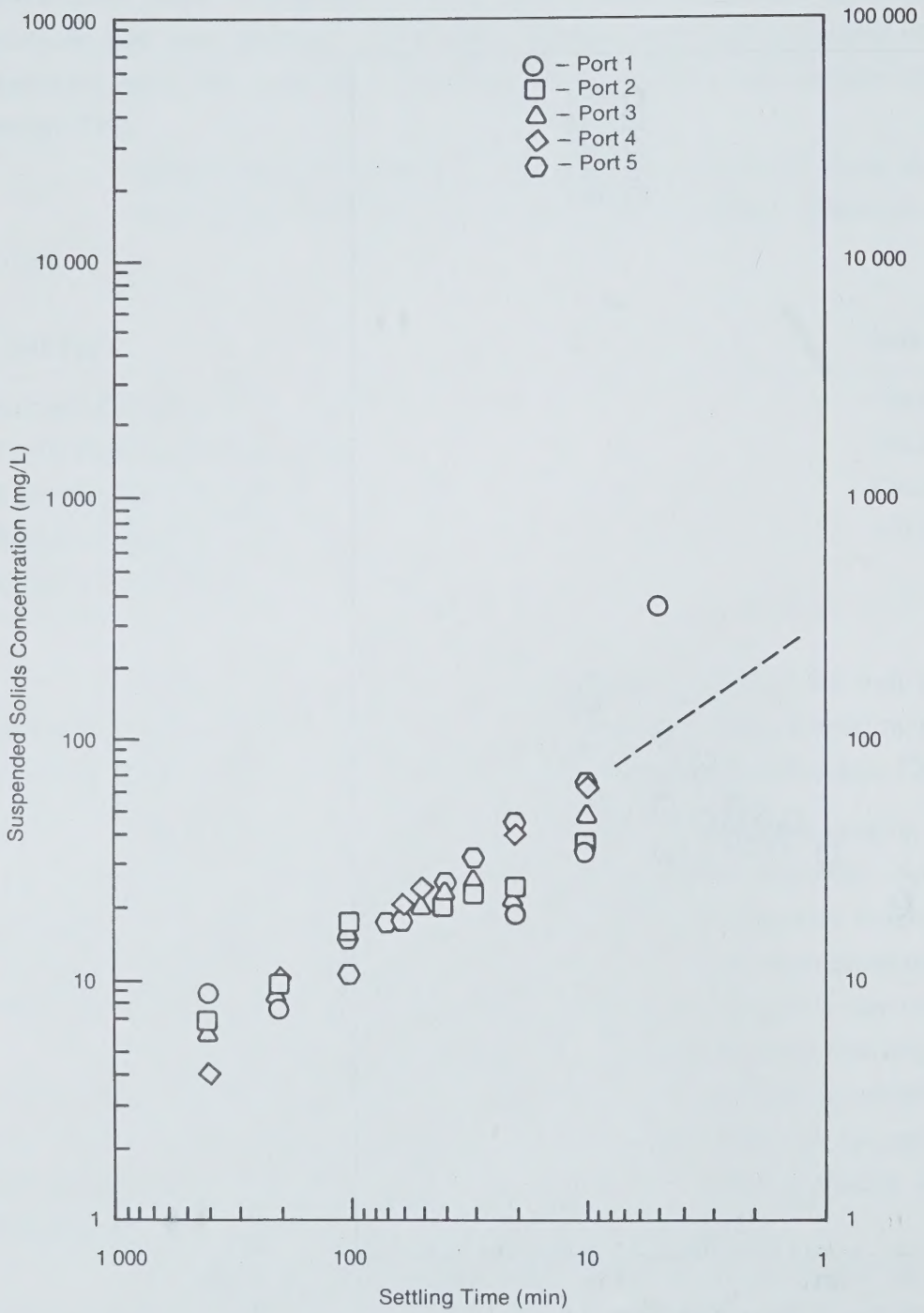


FIGURE 5 SETTLING CURVE OF BOTTOM ASH - ONE PERCENT BOTTOM ASH BY WEIGHT (13)

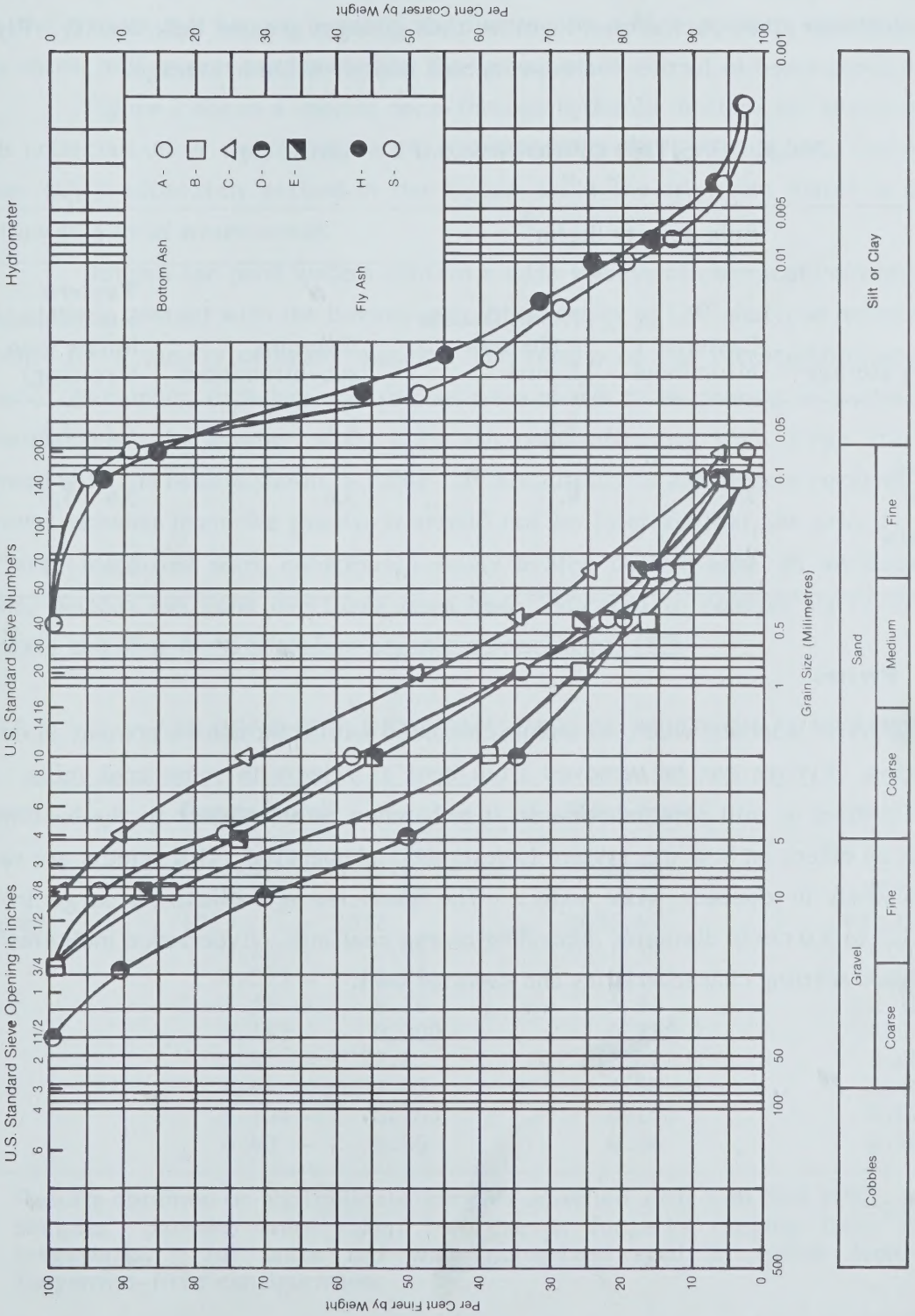


FIGURE 6 GRAIN SIZE DISTRIBUTION CURVES FOR BOTTOM ASH AND FLY ASH (20)

Table 8 indicates the bulk densities of fly ashes for four U.S. coals. Fly ash bulk densities are generally higher than those of bottom ashes from the same coals. Fly ash has a lower specific gravity than bottom ash but, because the fly ash particles are smaller in diameter, they pack closer together thus giving a greater bulk density. Fly ash can also be compressed to further increase its bulk density while in storage.

TABLE 8 BULK DENSITIES OF FOUR U.S. FLY ASHES (9)

	Bulk density (kg/m^3)			
Fly ash-dry storage	Eastern bituminous	North Dakota - Montana lignite	Wyoming sub-bituminous	Western Sub-bituminous (other than Wyoming)
Aerated	2.2	2.8	4.1	2.2 - 3.4
Silo storage (9 m deep)	3.4	4.1	5.6	3.4 - 5.0
Mechanically compacted	5.3	5.6	5.9	5.3 - 7.2

2.6 Pyrites

Pyritic sulphur, which is sulphur combined with iron, can be present in coal in several forms. Pyrites can be removed from coal as rejects in some coal mills. The disposal of pyrites or mill rejects, because it is handled as an adjunct to the bottom ash system, has an effect on how this system is designed and operated. Mill rejects are rather unreactive when in contact with water. The particles are relatively large in size averaging 1.5 to 3.0 cm in diameter depending on the coal mill. Experience indicates that they have good settling characteristics and dewater well.

3.0 BOTTOM ASH HANDLING SYSTEMS

In North America, bottom ash has traditionally been removed hydraulically from the bottom ash hopper beneath the furnace by a high pressure sluice system. In many cases, mill rejects are handled by the same system.

Figure 7 shows a typical once-through hydraulic bottom ash transport system. Solids collected under the furnace are transported as a slurry to a lagoon. The particulate bottom ash is ultimately settled in the lagoon while the transport water is allowed to overflow to a local watercourse.

Bottom ash pond waters contain a wide variety of chemical contaminants as a result of their contact with the bottom ash. Stephens et al (19) analyzed bottom ash pond effluents for a variety of heavy metals. The results of this investigation are shown in Table 9. Aluminum, cadmium and sodium were shown to be present in particularly high concentrations. In another study (22), ash pond effluents from three stations were analyzed with the results shown in Table 10. Because these ash lagoons received a number of waste streams from the plants, it should not be inferred that the priority pollutants that were identified were contributed solely by the bottom ash. In addition to trace metals, bottom ash pond overflows have been indicated to contain bis (2-ethyl-hexyl) phthalate and di-n-butyl phthalate organic contaminants (22).

TABLE 9 ASH POND EFFLUENT ANALYSES BY NEUTRON ACTIVATION*(19)

Element	Range (ppm)	Mean (ppm)	Std. Dev. (ppm)
Al	11.0 - 25.0	18.98	5.07
As	0.33 - 0.42	0.37	0.03
Cd (ppb)	1013 - 2332	1635.67	431.07
Cu	0.84 - 2.01	1.44	0.45
Hg	0.035 - 0.211	0.133	0.091
Mg	3.54 - 8.76	5.95	2.12
Mn	0.162 - 0.300	0.235	0.050
Na	11.8 - 22.8	17.07	3.68
Ti	0.64 - 2.05	1.37	0.55
V	0.104 - 0.165	0.140	0.020
Zn	0.40 - 0.80	0.56	0.15

* Results obtained on six replicate samples acidified with 5 ml 50% HNO_3 per litre of sample. Samples were taken from seven furnaces ranging from 40 to 500 megawatts. All units fed with pulverized coal in either front-fired or tangential-fired configuration.

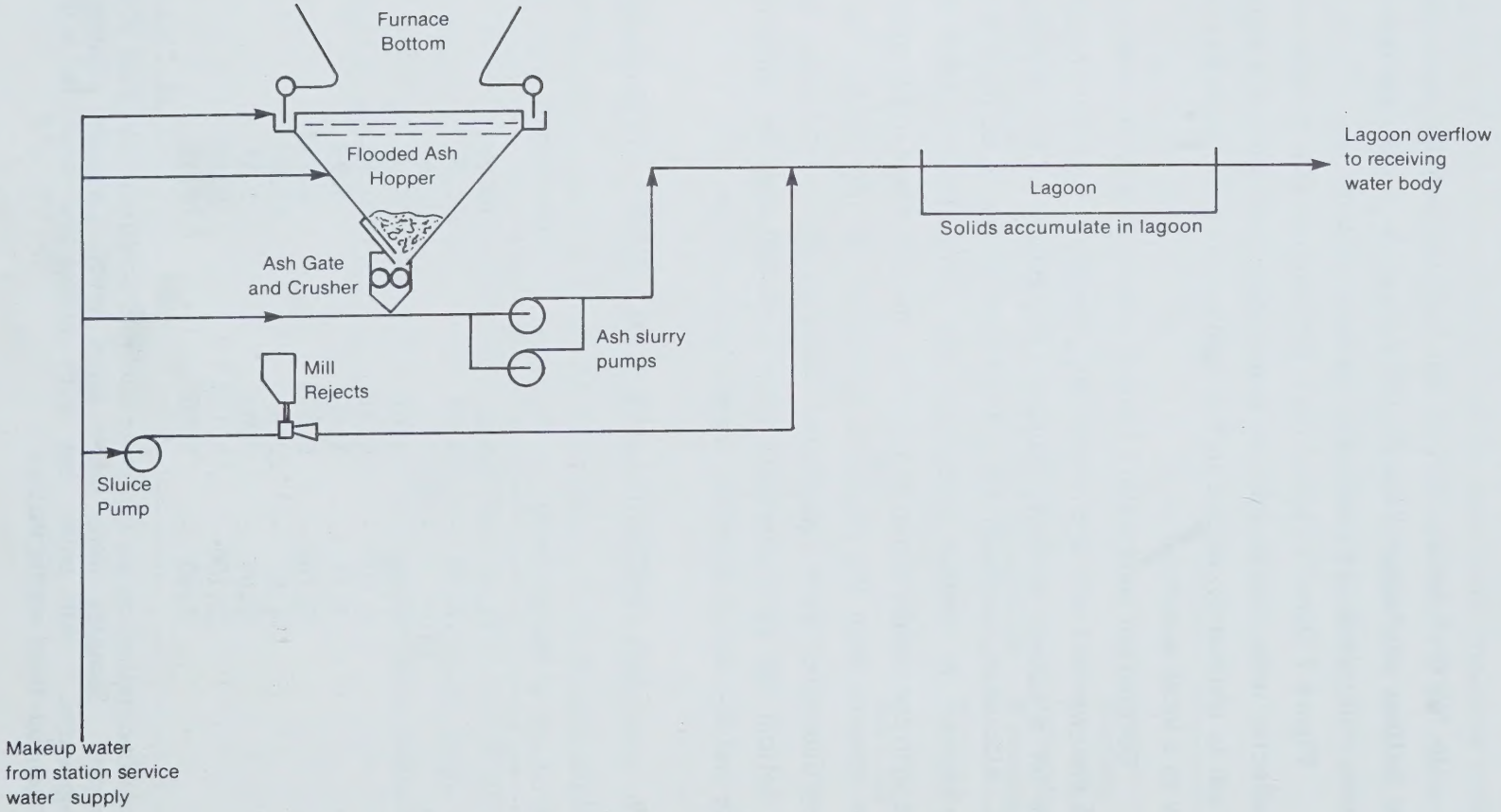


FIGURE 7 ONCE-THROUGH HYDRAULIC BOTTOM ASH TRANSPORT SYSTEM

TABLE 10 PRIORITY POLLUTANTS IDENTIFIED IN BOTTOM ASH TRANSPORT WATER STREAMS (22)

	Ash Pond Effluent (ppb)		
Organics*	Plant A**	Plant B**	Plant C**
Dibromochloromethane		< 1.0	
Chloroform	< 1.0		
Bromoform		< 1.0	
Benzene	2.0		1.0
Toluene	3.5		< 1.0
Phenol			4.1
Inorganics			
Antimony	6	7	5
Arsenic	< 1	9	74
Beryllium	2.5	< 0.5	< 0.5
Cadmium	1.0	2.0	< 0.5
Chromium	4	6	< 2
Copper	80	14	26
Lead	< 3	4	< 3
Mercury	< 0.2	< 0.2	< 0.2
Nickel	9.5	5.5	2.5
Selenium	3	8	42
Silver	5.5	0.5	1.0
Thallium	1	1	9
Vanadium	27	78	31
Zinc	300	7	11

* Organic analysis by gas chromatography and confirmed present by GC-MS.

** Plant A - unknown type of bottom ash transport system.
Plant B - once through bottom ash sluicing system.
Plant C - closed bottom ash sluicing system.

< Designates concentration below detection limit.

The presence of metals and priority pollutants in bottom ash transport water and the possible adverse environmental effects of these discharges has caused a re-evaluation of once-through bottom ash transport systems. In the United States, for example, guidelines for steam electric utilities compel stations to either treat to extremely high quality or reduce water use in bottom ash transport systems. The proposed effluent limitations specific to bottom ash transport water are shown in Table 11.

TABLE 11 U.S. ENVIRONMENTAL PROTECTION AGENCY EFFLUENT LIMITATIONS ON BOTTOM ASH TRANSPORT WATER (23)

	BPCTCA (July 1, 1977)		BATEA (July 1, 1983)		New Source	
	Avg*	Max	Avg*	Max	Avg*	Max
Total Suspended Solids (mg/L)	30	100	30**	100**	30***	100***
Oil and Grease (mg/L)	15	20	15**	20**	15***	20***
pH	-	-	6.0 to 9.0	-	-	-

* For 30 consecutive days.

** Allowable discharge is (flow x standard in mg/L)/ 12.5. The purpose is to encourage recycling to limit discharge flow rate.

*** Allowable discharge is (flow x standard in mg/L)/ 20. The purpose is same as noted above.

An examination of the best available technology economically achievable (BATEA) new source effluent limitations indicates how greatly the discharge from bottom ash transport systems has been limited. For example, to discharge the same concentration of total suspended solids as the July 1, 1977, best practicable control technology currently available (BPCTA) from a new source, the total discharge of the transport system must be reduced by a factor of 20.

Re-use of the ash transport water is the most economical means of attaining the objectives. For this reason, there has been considerable development work on the recycle alternatives for bottom ash transport waters in the United States. In Canada, concerns about the adverse environmental effects of bottom ash pond effluents have stimulated similar investigations of systems which reduce both water use and discharges of environmental contaminants.

3.1 Components of Bottom Ash Transport Systems

The major components in a wet bottom ash transport system are:

- bottom ash hopper,
- bottom ash grinder,
- ash slurry pumping system,
- mill rejects handling system,
- ash settling equipment.

Regardless of whether a bottom ash handling system recirculates the transport water or not, these components would be common. They are described individually in the following sections.

3.1.1 Bottom Ash Hopper. The larger boilers in electrical utilities require bottom ash hoppers with large storage capacities, steep self-feeding sloped sides and sufficient water containment to quench the bottom ash and to provide delivery at a high rate to the conveying system. The ash storage hopper is a self-contained, water-filled, refractory-lined, steel unit, with continuously water-cooled inner wall surfaces. These hoppers must be designed with adequate slopes for gravity feeding of the ash or slag which may fall into the hopper. The design may be modified for unusual conditions of slagging or high ash content coal by increasing the hopper width under the seal troughs or by lengthening the hopper. Discharge openings, on the bottom slopes, aid in the unrestricted flow of ash from the hopper.

Usually two or three "V" shaped compartments hold the collected bottom ash until it is discharged. The ash storage hopper seals the furnace floor and provides storage space for the bottom ash. This allows for efficient periodic removal of the ash with a minimum of effect on the furnace operation.

The hopper walls and floor are sloped to funnel the ash toward the ash gates in each of the hopper compartments. The outer hull of the hopper is usually 9.53 mm steel plate. A poured refractory lining protects the outer steel shell from the furnace heat and resists abrasion by the ash. The refractory lining is continuously cooled by a water curtain supplied by the overflow weir boxes. A water-filled seal trough on the outer periphery of the ash hopper provides a positive seal between the ash hopper and the steam generator. Details of the seal trough and weir box are shown in Figure 8. It also provides for the downward and lateral expansion of the furnace without placing stress on the ash hopper.

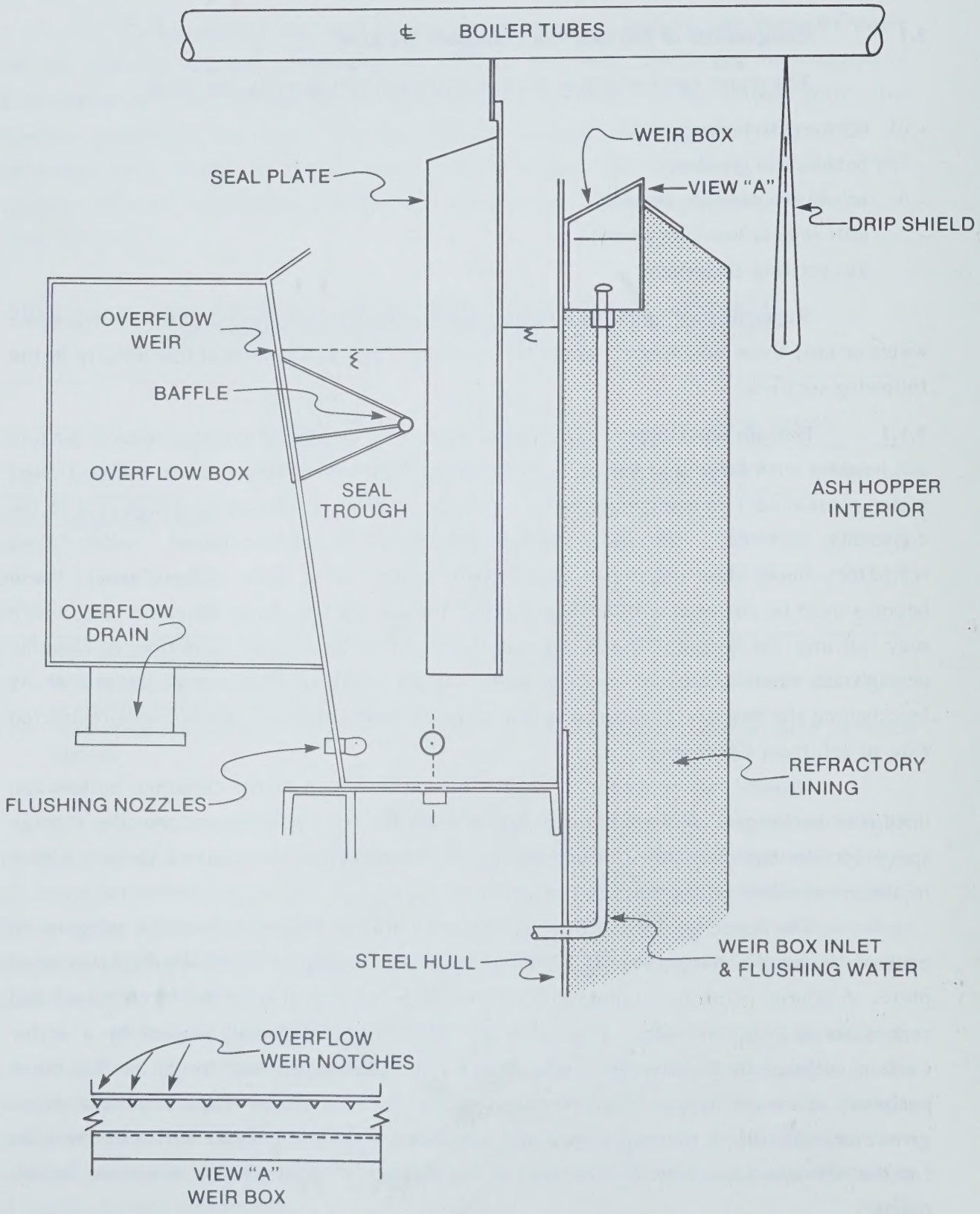


FIGURE 8 SEAL TROUGH AND WEIR BOX OF A TYPICAL BOTTOM ASH HOPPER

The seal plate is part of the boiler structure. A series of weir boxes or similar devices around the top periphery of the hopper permits the overflow of a continuous curtain of cooling water. Because the trough is exposed to furnace gases and high temperatures, it is constructed of stainless steel or other corrosion and temperature-resistant metals.

A continuous water flow is provided for cooling and makeup. The makeup is required due to the evaporation of the contained water in the furnace. Intermittent water is supplied for flushing. The seal trough is flushed automatically during the remote ash removal operation as the ash hopper is filling to the normal high water level after all the compartments have been emptied.

In a closed sluicing system, these waters are supplied from the recycle system.

3.1.2 Bottom Ash Grinder. The collected bottom ash passes through a discharge gate from the hopper to the bottom ash grinder. Single or double-roll clinker grinders are provided in various capacities to crush the accumulated slag or ash. The grinder is sized so that the ash is crushed and fed at a steady rate without extreme fluctuation.

Typically, a grinder is driven by 3.73 to 18.64 kW electric motor. A motor reducer with fluid coupling, chain and sprocket drive transmits the power to the grinder. Two manganese steel rolls on fixed centres rotate toward each other. These rolls have teeth which are integrally cast with the rolls. The teeth and roll combinations grind the ash to a desired size, usually about 50.8 mm in diameter, for conveyance through the transport piping system.

Cooling and service water is supplied to the ash grinder seals from service water. Water is supplied to the seals at all times to prevent damage to the grinder shafts by the abrasive ash. Clinker grinders and ash hopper gates are usually over-sized to provide insurance against outages because of variations in fuels. In large boilers where the characteristics of the ash cannot be predicted well in the design stage, this is particularly important. On large hoppers, for insurance, a redundant discharge gate and grinder are installed on each hopper segment. This allows one system to be maintained while the backup one is in operation. When light ash loads are expected, a single roll crusher can be used.

3.1.3 Pumping System. Once the ash has been collected, discharged and crushed, it is fed into an adapter or sump from which it flows into a pump system. Typically either a centrifugal material handling pump or an ejector (jet pump) is used. With either pump,

considerable dilution is required at the suction side to provide a slurry which can be pumped. The solids may be present as 1 to 20 percent of the total weight of the slurry. A 1 percent solids slurry appears to be characteristic of U.S. steam electric generating stations (24); however, five to ten percent solids in water slurry may be more common in Canada. The suction of a jet pump is limited by the system head which also determines the amount and pressure of the jet impulse water.

The bottom ash jet pump uses water from the bottom ash sluice water pumps, providing a high pressure water jet which issues from a nozzle at high velocity. This entrains and mixes with the bottom ash and discharges through a diverging throat into the transport line. The jet pump throat is composed of abrasion-resistant material to resist erosion by the ash. The pressure nozzle tip is constructed of tungsten carbide material to alleviate erosion problems. All joints must be well sealed since this seriously affects the efficient operation of the jet pump.

A centrifugal pump pulls the same amount of sluicing water through its suction line as it delivers to the discharge line. To prevent overloading, a special fitting is provided when the pump is directly connected to an ash hopper outlet. Dilution water is added to control the specific gravity of the slurry discharged by the pump.

For the same discharge quantity and discharge head, a centrifugal pump is about 40 percent more efficient than a jet pump. This does not consider the auxiliary pumping equipment which supplies the ejector nozzle. Jet pumps are favoured because of their easy service, although such service may be required more often than with a comparable centrifugal pump.

Hard metals are employed in the construction of either pump. Abrasive wear increases with increased velocities through the pumps. Jet pumps are generally ineffective when system heads exceed 30.5 m since series pumping is impractical. For high level requirements, centrifugal pumps can be operated in series.

Centrifugal pumps have an important advantage in recirculating systems. The high pressure required by ejector nozzles is extremely wearing on the jet nozzle and the pumps which bring water from the conveying system to the jets. The quantity of the recirculated water is not a problem with centrifugal ash handling pumps. Clean water must be provided for gland seals. A self-cleaning filter can be used to purify a portion of the supply water for seal use. Also, when centrifugal pumps are used, return water pumps deliver water at a relatively lower pressure.

Because the bottom ash slurry is very abrasive, special consideration is given to the type of material used for transport pipes and valves. Hard iron alloy pipe is used for ash conveying lines. Bend and lateral fittings are modified to combat the abrasive action in the conveying line.

Ash transport lines are usually sloped so they are self-draining. Drains provided at low points transport water from the lines to the recycle basin in a recycling system. The drain valves prevent freezing of the drain backwater during winter months.

Sleeve type couplings used are compatible with plain end pipe and fittings, allowing easy replacement and rotation of the pipe for extended service.

When two lines merge or it is necessary to direct flow, oversized butterfly type valves are used. Adaptor castings at both the inlet and outlet allow the valve disc to be swung out of the direct flow of solids, reducing turbulence and function losses. Valves are equipped with manual or cylinder operators.

3.1.4 Mill Rejects Handling System. Along with bottom ash, hydraulic systems often also handle coal mill rejects or pyrites. Storage hoppers are mounted below each coal mill discharge spout to receive rejects. The rejects are removed in sequence from such hoppers to a central storage bin by jet pumps. The hoppers are constructed of carbon steel with overflow seals. The holding bins for the rejects are sized to provide sufficient capacity so that they can be emptied on the same cycle as the bottom ash hoppers serving the same boiler unit.

Because the mill rejects are heavier than ash, a greater flow is required to convey the rejects. Usually a jet pump of the same size as the bottom ash pump is used to discharge the mill rejects through the same line as the bottom ash.

In some stations, mill rejects have been discharged into the bottom ash hopper. However, this is no longer considered practical as boiler tubes can be damaged by splashing from the mill rejects discharge pipes. Also, the resultant slurry removed by the bottom ash system is not uniform in density and may cause line plugging.

3.1.5 Ash Settling Equipment. Bottom ash can be removed from the bottom ash sluice water in a lagoon or a hydrobin (dewatering bin) system. A lagoon should preferably be lined or constructed of impervious material to minimize infiltration of the ash water contaminants into the groundwater system. To be effective, sufficient retention time should be provided in the lagoon for the ash to fully settle. Sedimentation is the major process by which this separation occurs. The settling properties of bottom ash are such

that the volume of the basin should provide a retention time of about one day based on the ash transport water flow rate.

Lagoons may be used for permanent or temporary storage of the settled bottom ash. When a lagoon is used for temporary ash storage, it is normally divided into two or more parallel basins. This permits one compartment to be dredged out while another compartment of the basin continues to receive the bottom ash slurry. If the ash pond is used for ultimate disposal, it settling performance will decay as the lagoon fills with ash and the retention time shortens.

Hydrobin ash dewatering is often used at generating stations where the site area does not permit the use of ash lagoons or where water supplies are limited. A bottom ash handling system which utilizes hydrobins has three main components: hydrobins, a settling tank, and a storage tank. A typical system is shown in Figure 9.

Ash is pumped into a bin over a bar screen which permits the finer material to drop directly into the center while the coarser materials are diverted toward the sides of the bin. The outer layer of coarser ash acts as a filter and traps fines before they reach the decanting elements.

Excess water overflows a serrated weir around the bin periphery when the bin is full. From a collection trough, it flows by gravity through a drain pipe to the settling system. The dewatering bin contains several components which include an underflow baffle, concentric with the outer shell of the bin. All material must pass under this baffle before reaching the overflow weirs. This baffle also reduces turbulence in the bin. The overflow trough drain discharges into the centre of the settling tank. Dewatering bins are usually constructed of carbon steel with the lower core section forming an angle of 60 degrees with the horizontal. Vibrators can be installed to allow the dewatered ash to be removed more easily.

Dewatered ash is removed through a large-diameter water collecting gate, which is actuated by a large-diameter hydraulic cylinder. A sealing tube in the gate frame prevents water leakage. Each gate can be equipped with strip heaters to protect against freezing. A fixed chute is provided below each gate for discharging the dewatered ash and pyrites into trucks for removal.

Dewatering bin sizing, in addition to providing for dewatering cycles, is generally determined by the longest period during which it may not be possible to unload them. This is usually considered to be a weekend. If the bottom ash has cementing properties, more frequent unloading from a larger number of small bins is desirable.

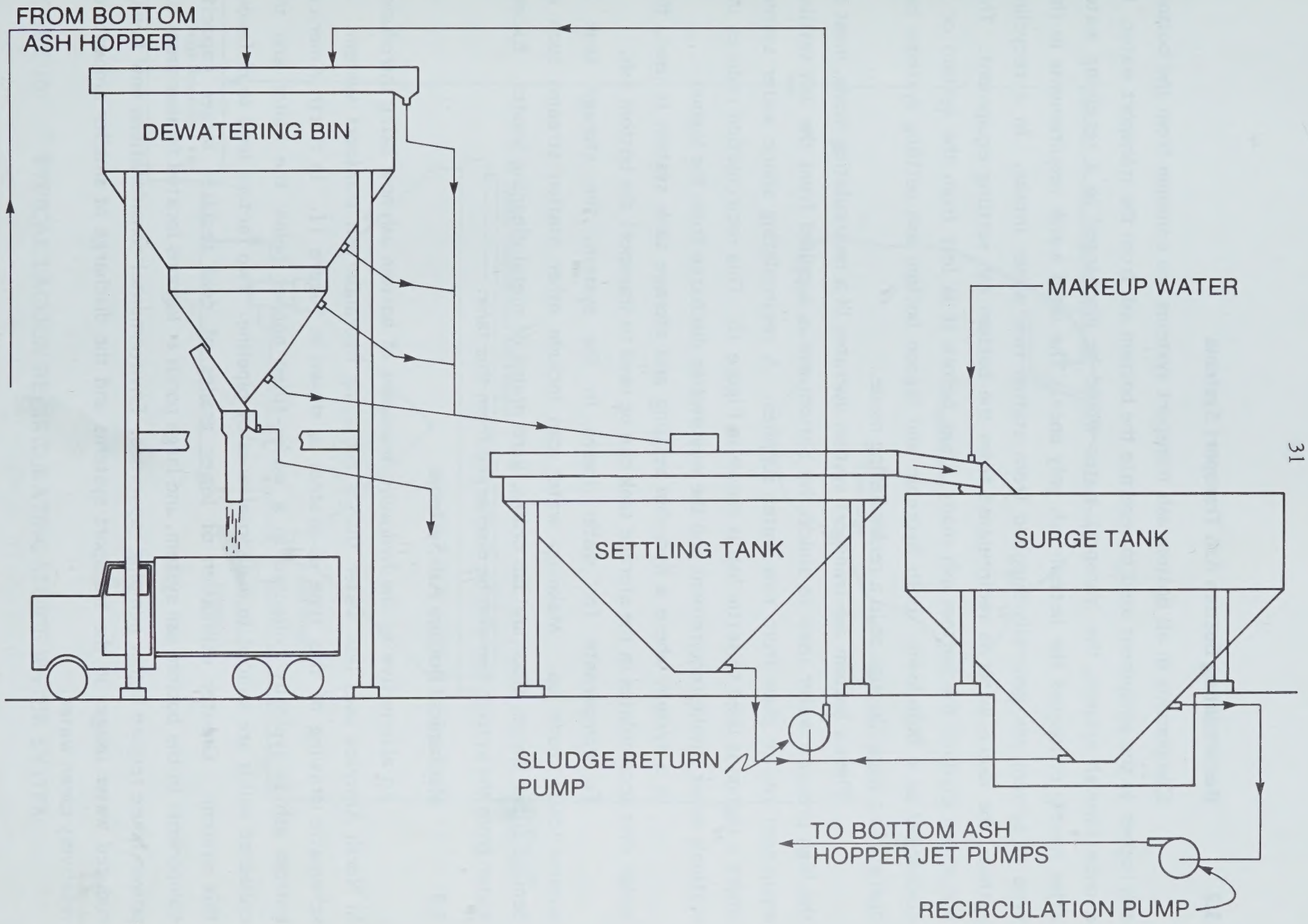


FIGURE 9 TYPICAL HYDROBIN RECIRCULATING SLUICE WATER SYSTEM (25)

3.2 Recirculating Bottom Ash Transport Systems

Components in all bottom ash transport systems are common from the bottom ash hopper to the equipment used to separate the bottom ash from the transport water. In a once-through system, the transport water would be discharged to a receiving water after having contacted the bottom ash only once. The total water requirements in this type of system are generally supplied from station raw water intake. In a recycling system, the sluice water is recirculated from the bottom ash settling equipment. This water can contact the bottom ash many times before it is lost from the system or is discharged as a blowdown. Both hydrobin and lagoon bottom ash settling systems can operate in a once-through or in a recirculating mode.

When a bottom ash transport system operates in a recirculating mode, most of the high pressure water used to sluice the bottom ash is supplied from the ash settling equipment rather than from raw water supplies. A recirculating sluice water system where a lagoon is used to settle ash is shown in Figure 10. This recirculation reduces the station's water intake requirement and the wastewater discharge from the lagoon.

In a system where a hydrobin settling and storage tank system is used, the water that accumulates in the storage tank can be used to transport the bottom ash.

To compensate for water losses in the system, the storage tank is automatically made up. Make-up water can include other station streams such as demineralizer water, floor and lab drains, yard drains or metal cleaning wastes. Excess water from the system can also be discharged from this tank.

3.3 Mechanical Bottom Ash Systems

An alternative to the hydraulic transport of bottom ash now being introduced in North America uses less water than a recycling hydraulic ash transport system. A schematic drawing of this type of system is shown in Figure 11. In North America, bottom ash is typically collected in a water-filled hopper below the boiler and the collected solids are sluiced to a disposal area by pipeline. Two factors tend to disfavour this system. Greater utilization of lower grades of coal requires larger capacity components in the bottom ash system, and large ponds or lagoons located farther from the power-house require higher pumping capacities. Environmental considerations now favour reduced water usages in the transport systems and the discharge of smaller amounts of relatively clean water.

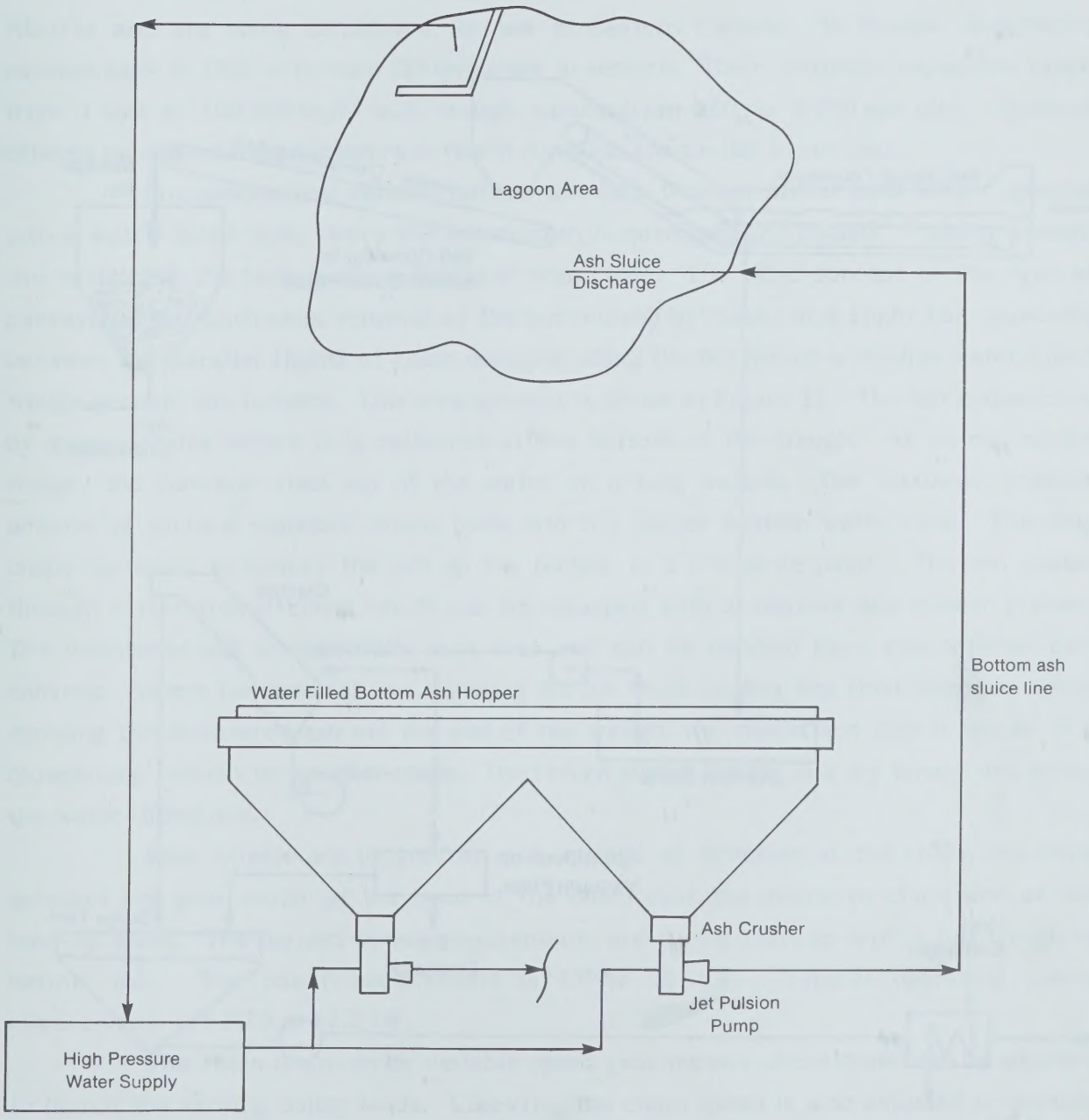


FIGURE 10 TYPICAL LAGOON RECIRCULATING SLUICE WATER SYSTEM

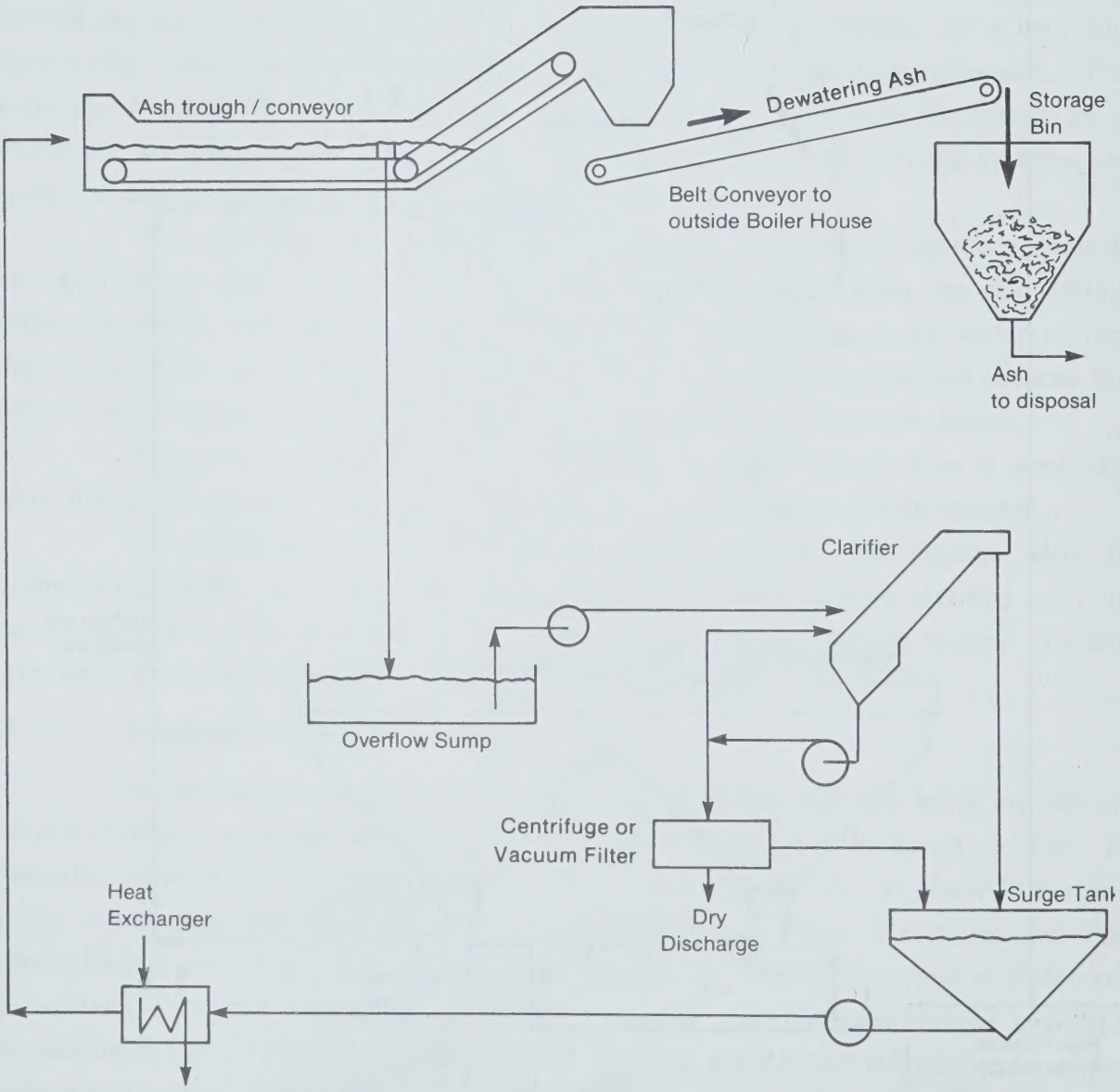


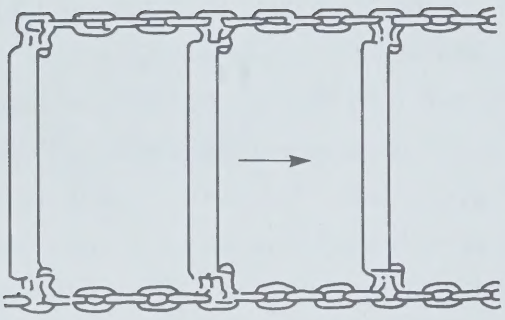
FIGURE 11 SCHEMATIC FLOWSHEET OF WATER FLOW IN A TYPICAL MECHANICAL ASH TRANSPORT SYSTEM

Some European stations use a mechanical chain conveyor system to remove ash from the boiler bottom hopper continuously and dewater it. This technology is now being offered in North America by several of the larger vendors of ash systems. Mechanical bottom ash removal systems have been ordered by utilities in Missouri and Alberta and are being considered for use in Eastern Canada. In Europe, experience extends back to 1957 with over 189 units now in service. Their maximum capacities range from 1 000 to 100 000 kg/h with trough widths from 800 to 2 200 mm (26). Systems offered by various manufacturers in North America are similar in concept.

In a mechanical system, bottom ash falls through the furnace hopper opening into a water-filled tank. Here the bottom ash is quenched and cooled. Passing through the bottom of the tank is the submerged drag chain. The basic concept of this type of conveyor is the continuous removal of the bottom ash by means of a flight bar suspended between two parallel flights of chain dragging along the bottom of a shallow water-filled trough beneath the furnace. This arrangement is shown in Figure 12. The ash is quenched by spray nozzles before it is collected at the bottom of the trough. At an end of the trough, the conveyor rises out of the water on a long incline. The maximum possible amount of surface moisture drains back into the hopper bottom water tank. The drag chain continues to convey the ash up the incline to a discharge point. The ash passes through a transitional chute which can be equipped with a vibrator and clinker grinder. The dewatered ash is essentially dust-free and can be handled by a conventional belt conveyor system for removal to a handling bin for truck loading and final disposal. After dumping the dewatered ash off the end of the trough, the chains and flights return in a closed-loop fashion for another cycle. The return strand travels in a dry trough just below the water-filled one.

Idler wheels are located at each change of direction of the chain, the drive sprocket and gear motor at the head of the chain near the discharge chute and at the take-up spool. The highest power requirements are during start up with a full trough of bottom ash. The power requirement is 15 to 30 kW. Typical operating power requirements are 3.75 to 11.2 kW.

The chain is driven by variable speed gear motors whose speed can be adjusted to match the varying boiler loads. Likewise, the chain speed is also adjusted to provide most efficient operation so that the drag links carry a full load and thus reduce unnecessary wear in the equipment. The drag bars are designed on expected ash production rate.



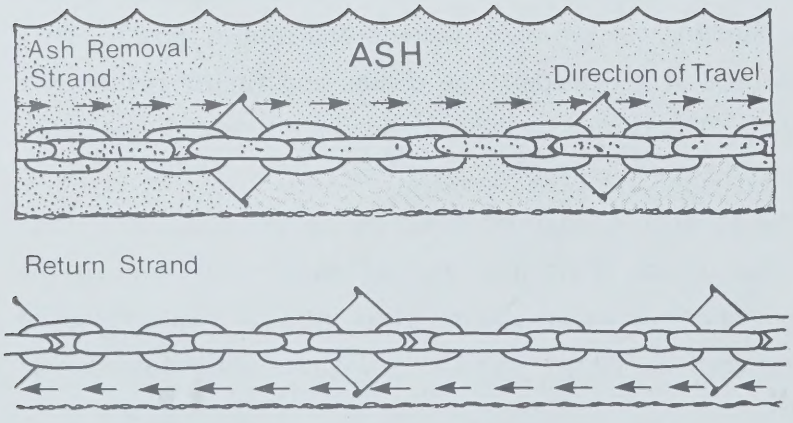


FIGURE 12 DRAG BAR AND CHAIN ASSEMBLY (27)

The angle of the inclined portion of the system is dependent on the available space and nature of the ash to be removed. Fine ashes tend to slide back toward the water-filled hopper. Large pieces must be able to pass all the minimum clearances in the trough and must not roll backwards down the incline.

A transitional chute is used to adapt the boiler bottom to the relatively narrow water trough below the bottom. This must seal to the boiler bottom and allow for its downward and lateral expansion. All of the various transition chute configurations have dry sloping sides and shallow water troughs below. Slag, falling from the furnace during soot blowing or load changes, may damage the chute or the ash removal system.

The transitional chute is supplied with service water for quenching sprays, water curtains for refractory cooling inspection windows, and breaker bars. A 1 to 1.25 m water depth is kept in the trough to keep the inclined portion of the chain system as short as possible. Water losses are minimized with this system. Some water evaporates into the boiler due to furnace radiation and exposure to the hot ash. Water is also entrained in the ash as it is removed from the drag chain system. This is typically 25 percent moisture by weight. The water makeup to this system is 2 to 8 L/s compared to 126 L/s for a hydraulic ejector system (27). This comparison is for a theoretical 400-MW unit using coal with an ash content of 10 percent.

The quenching water, seal trough makeup, shaft seal water and makeup water to the ash trough is recirculated. The trough water is maintained at a temperature of 60°C or below. A heat exchanger used to maintain this temperature is sized depending on the quantity of ash produced and boiler size. It is possible to recover some low grade heat from the ash using this approach.

Overflow water from the drag chain trough is discharged through a parallel plate arrangement at low velocities to minimize solids loss. Suspended solids levels are as low as 250 mg/L. Cooling water for the system can be supplied from river water or cooling tower blowdown water to maintain the desired temperature. The possibility of scaling in the trough has been considered in the design. A light $CaCO_3$ scaling may be considered an advantage as it would reduce abrasion and spalling. It is felt that the continuous makeup to the system keeps the scaling elements below their solubility product concentrations.

Mechanical ash systems have been successfully used in Europe because of the operating conditions on that continent. These include type and quantity of ash from European coal, land area available for power plant operation and availability of water.

The lower BTU coals used in Europe produce a smaller, more uniform ash particle which tends to be more predictable for ash equipment design and less abrasive.

The major environmental benefit of the mechanical ash removal system is the reduced water usage compared to hydraulic systems. Other advantages include eliminating the need for lagoons or hydrobin systems. Since the bottom ash is removed continuously, the problems associated with removing accumulated ash are eliminated. Removal rates for ash can be varied without changing the demand for transport water.

A problem with this system is the lack of storage capacity for intermittent operation, no redundancy of equipment, high number of moving parts subject to wear and the necessity to shutdown the unit if the ash removal system fails. Many systems now use basalt lined troughs and easily replaceable wear parts where there is contact between moving and stationary parts. Renewable wear pads, wear strips and replaceable chain links are a common feature of this design. At present this system appears to be best suited for stations using lignite coal which resemble those used in Europe. An economic assessment of mechanical bottom ash systems is presented in an appendix to this report.

3.4 Water Requirements for Bottom Ash Sluicing

Water used for the hydraulic removal of bottom ash from the combustion area represents a significant service water demand. For plants operated by the Tennessee Valley Authority, ash sluicing water requirements average about 0.51 m^3/s per 1 000 MW generating capacity. The water requirements for sluicing bottom ash in the United States range from 4.12 to 151 m^3 per tonne of bottom ash (28). It is not stated which water uses in the bottom ash transport system are included in the estimates. The water requirement to sluice the bottom ash as a one percent slurry would be 99 m^3 per tonne of bottom ash.

The water requirements for the hydraulic sluicing of bottom ash and pyrites for a 952-MW pulverized coal fired plant in the United States (29) are summarized in Table 12. These values are roughly representative of other coal-fired stations in North America. Cooling and sealing of the weir surrounding the bottom ash hopper is continuous and requires 30 percent of the total water requirement of bottom ash and pyrites sluicing. Almost 59 percent of the water is used intermittently for the transport of bottom ash. This includes water used for sluicing of bottom ash and flushing of transport lines. Pyrites sluicing requires about 10 percent of the total use of water and is intermittent. Other miscellaneous uses make up a relatively small fraction of the total usage.

TABLE 12 WATER REQUIREMENTS FOR BOTTOM ASH AND PYRITES SLUICING (29) Gaston C. Ernest Generating Station, Southern Electric Generating Co., Wilsonville, Alabama. A 952-MW unit fuelled by pulverized coal.

Duty		Low Rate (L/s)	Duration (min/shift)	Percent of Total
Unit 1:	Sluicing	123.68	73	-
	Flushing	37.86	15	-
Unit 2:	Sluicing	123.68	60	-
	Flushing	37.86	20	-
Unit 3:	Sluicing	123.68	47	-
	Flushing	37.86	15	-
Purge		123.68	3 x 8 each	-
Fill		94.65	3 x 15 each	-
	SUB TOTAL			58.8
COOLING AND SEALING				
Cooling Weirs		34.07	Continuous	30.9
PYRITE SLUICING				
Pyrites Tank		167.85	12	-
Purge		167.85	8	-
Pyrites Tank Makeup		40.38	12	-
Mill Rejects		32.50	7 x 6 each	-
	SUB TOTAL			9.9
MISCELLANEOUS				
Grinder Seal		0.50	180	-
Pressure Transfer		0.06	210	-
Bubblers		0.25	Continuous	-
	SUB TOTAL			0.4
TOTAL, BOTTOM ASH HANDLING				100

3.5 Factors Influencing the Operation of Recirculating Systems

A bottom ash transport system operated as a recirculating water system requires that the transport water from the ash settling equipment be recirculated to the ash hoppers to sluice the ash. In a recirculating system, three factors control the quantity and frequency of discharge of the ash transport water. These are:

- hydraulic considerations,
- chemical considerations,
- mechanical problems.

3.5.1 Hydraulic Considerations. In a closed-cycle bottom ash transport system, water uses must balance. That is, any increase in water entering the system must have a compensating water loss from the system. Excess water in a bottom ash system can result from other waste streams entering the system, excessive make-up water, or input from precipitation or runoff into the lagoon or hydrobin. Potential water losses include occlusion with the removed bottom ash, evaporation into the furnace, evaporation from the lagoon or hydrobins, leakage from hydrobins and seepage from lagoons.

If the volume of water entering the system exceeds the water losses, then a blowdown will be required. The magnitude of this excess will determine the amount and frequency of the discharge.

Weir cooling water and pyrites sluicing require about 30 and 10 percent of the bottom ash transport water volume respectively as shown in Table 12. In a station where water for either of these uses is supplied from raw water supplies and not from the recirculated system, a significant excess of water could result unless these inputs are compensated for by large water losses due to evaporation or occlusion in the ash. In this situation it would not be possible to operate a fully-closed system.

When a lagoon is used to settle the bottom ash from the transport water, precipitation and surface runoff can accumulate and result in an excess of water. If the precipitation exceeds the normal losses or there is insufficient storage capacity to handle temporary overloads, then the excess water accumulated in this way would have to be discharged.

In some stations the ash lagoon or hydrobin may receive other wastewater streams such as demineralization wastes, coal pile runoff or yard drains. If the water volume from these sources exceeds the losses in the bottom ash transport system, then this excess water volume would have to be discharged as well.

In some bottom ash systems, flushing and sluicing flows are intermittent and are controlled manually by operators. If more water is used by the operator to perform a specific task than is allowed for in the system design, an excess of water above the recirculation rate capability can result. This would also necessitate a blowdown in systems which do not have a capacity to handle surges in water input.

3.5.2 Chemical Considerations. A second factor which can limit the complete closing of the bottom ash transport system is accumulation of dissolved chemical constituents in the bottom ash transport water. As the transport water is recycled there is increased contact between the bottom ash and the sluice water. This can eventually produce increased concentrations of chemical constituents to a point where these can exceed their solubility limits and form scale.

The different properties of fly and bottom ash affect the degree to which many chemical constituents in each can be readily dissolved in the sluice water. The smaller size and consequent greater surface area per unit weight of the fly ash particles permits a good deal of surface adsorption of elements from the flue gas stream. As a result considerably more of the trace elements in fly ash are adsorbed on the particles' surfaces than in bottom ash and can be readily leached by sluiced water.

Bottom ash and slag are vitrified during the combustion process and the elements present tend to be more uniformly distributed in the body of the bottom ash particle. Bottom ash also has a lower surface area per unit weight than fly ash, so there is less room for elements to accumulate on the surface. For these reasons, many of the chemical constituents of bottom ash are not as readily dissolved or dispersed in the sluice water.

The characteristics of ash pond waters have been reported in a characterization study (28) and are shown in Table 13. The reported values include the background concentrations in the raw water supplied to the system.

These bottom ash ponds were shown to have lower concentrations of calcium, sulphate and silica than fly ash ponds of the same stations. This suggests that bottom ash transport water would be less likely to form scale.

Similar results from another study are presented in Table 14. Bottom ash pond effluents were shown to contain lower total hardness, total dissolved solids, sulphate and calcium concentrations than fly ash pond waters. Chu, Nicholas and Ruane (30) reported that recycling bottom ash sluice water without some form of treatment would eventually

TABLE 13 CHARACTERISTICS OF DISCHARGES FROM ONCE-THROUGH ASH PONDS (28)

Water quality constituent	Plant A		Plant B	
	Fly ash pond (Avg)	Bottom ash pond (Avg)	Fly ash pond (Avg)	Bottom ash pond (Avg)
Flow* (L/s)	392	1 019	-	-
Total Alkalinity (mg/L)	-	85	54	78
Phen. Alkalinity (mg/L)	0	0	3	45
Conductance* (μmhos/cm)	810	322	242	650
Total hardness* (mg/L)	260.5	142	108	302
pH*	4.4	7.2	8.0	9.8
Dissolved solids* (mg/L)	508	167	142	524
Suspended solids* (mg/L)	62.5	60	64	85
Aluminum (mg/L)	7.2	3.5	1.8	2.8
Ammonia as N (mg/L)	0.43	0.12	0.07	0.09
Arsenic (mg/L)	0.010	0.006	0.03	0.018
Barium (mg/L)	0.3	0.2	0.1	0.1
Beryllium (mg/L)	0.01	< 0.01	< 0.01	< 0.01
Cadmium (mg/L)	0.037	0.001	0.001	0.003
Calcium (mg/L)	136	40	142	63
Chloride (mg/L)	7	8	6	7
Chromium (mg/L)	0.067	0.009	0.02	0.01
Copper (mg/L)	0.31	0.065	0.02	0.041
Cyanide (mg/L)	< 0.01	< 0.01	< 0.01	< 0.01
Iron (mg/L)	1.44	5.29	1.93	5.98
Lead (mg/L)	0.06	0.02	0.01	0.02
Magnesium (mg/L)	14	5.9	3.9	6.9
Manganese (mg/L)	0.48	0.16	0.13	0.58
Mercury (mg/L)	0.0003	0.0007	0.001	0.001
Nickel (mg/L)	1.1	< 0.05	0.05	0.12
Total Phosphate as P (mg/L)	0.02	0.08	0.08	0.07
Selenium (mg/L)	0.002	0.002	0.015	0.011
Silica (mg/L)	12.6	7.4	8	7.7
Silver (mg/L)	< 0.01	< 0.01	< 0.01	< 0.01
Sulphate (mg/L)	358	49	209	139
Zinc (mg/L)	1.51	0.09	0.06	0.14

* Weekly grab samples during 1973 and 1974.

TABLE 14 CHARACTERISTICS OF ASH POND EFFLUENTS (30)

	Plant A, 1973				Plant B, 1973			
	Fly Ash		Slag		Fly Ash		Bottom Ash	
Flow	397 L/s	37.6 m^3/tonne	1064 L/s	43.3 m^3/tonne	55 L/s	48 m^3/tonne	146 L/s	126 m^3/tonne
pH	4.5		7.1		9.8		8.0	
	mg/L	kg/kg ash	mg/L	kg/kg ash	mg/L	kg/kg ash	mg/L	kg/kg ash
Total alkalinity (as $CaCO_3$)	-	-	82	3.54×10^{-3}	-	-	54	6.80×10^{-3}
Phenol alkalinity (as $CaCO_3$)	-	-	0	0	-	-	0	0
Total hardness (as $CaCO_3$)	241	9.05×10^{-3}	153	6.61×10^{-3}	550	2.63×10^{-2}	108	1.36×10^{-2}
TDS	508	1.91×10^{-2}	176	7.60×10^{-3}	615	2.94×10^{-2}	142	1.79×10^{-2}
Suspended solids	87	3.27×10^{-3}	66	2.85×10^{-3}	23.5	1.12×10^{-3}	64	8.06×10^{-3}
Phosphorous	0.07	2.63×10^{-6}	0.21	9.07×10^{-6}	0.25	1.20×10^{-5}	0.09	1.13×10^{-5}
Ammonia (as N)	0.16	6.01×10^{-6}	0.1	4.32×10^{-6}	0.11	5.26×10^{-6}	0.17	2.14×10^{-5}
Sulphate	383	1.44×10^{-2}	54	2.33×10^{-3}	301	1.44×10^{-2}	168	2.11×10^{-2}
Chloride	8	3.00×10^{-4}	9	3.89×10^{-4}	6	2.87×10^{-4}	8	1.01×10^{-3}
Cyanide	< 0.01	$<3.76 \times 10^{-7}$	< 0.01	$<4.32 \times 10^{-7}$	< 0.01	4.79×10^{-7}	< 0.01	1.26×10^{-6}
Silica	13.8	5.18×10^{-4}	7.5	3.24×10^{-4}	9.9	4.74×10^{-4}	11.2	1.41×10^{-3}
Calcium	170	6.39×10^{-3}	44	1.90×10^{-3}	211	1.01×10^{-2}	56	7.05×10^{-3}
Magnesium	13.4	5.03×10^{-4}	4.9	2.12×10^{-4}	4.3	2.06×10^{-4}	9.1	1.14×10^{-3}
Aluminum	6.6	2.48×10^{-4}	3.1	1.34×10^{-4}	2.5	1.20×10^{-4}	3.4	4.28×10^{-4}
Arsenic	0.01	3.76×10^{-7}	< 0.005	$<2.16 \times 10^{-7}$	0.03	1.43×10^{-6}	< 0.02	2.52×10^{-6}
Barium	0.2	7.51×10^{-6}	0.1	4.32×10^{-6}	0.1	4.79×10^{-6}	0.2	2.52×10^{-5}
Beryllium	0.01	$<3.76 \times 10^{-7}$	< 0.01	$<4.32 \times 10^{-7}$	< 0.01	4.79×10^{-6}	0.01	1.26×10^{-6}
Cadmium	0.037	1.39×10^{-6}	< 0.001	$<4.32 \times 10^{-8}$	< 0.001	4.79×10^{-8}	0.002	2.52×10^{-7}
Chromium	0.03	1.13×10^{-6}	< 0.005	$<2.16 \times 10^{-7}$	< 0.01	4.79×10^{-7}	< 0.01	1.26×10^{-6}
Copper	0.32	1.20×10^{-5}	0.05	2.16×10^{-6}	0.02	9.57×10^{-7}	0.09	1.13×10^{-5}
Iron	0.74	2.78×10^{-5}	3.85	1.66×10^{-4}	3.3	1.58×10^{-4}	9.8	1.23×10^{-3}
Lead	0.04	1.50×10^{-6}	< 0.01	$<4.32 \times 10^{-7}$	< 0.01	4.79×10^{-7}	< 0.02	2.52×10^{-6}
Manganese	13.38	5.03×10^{-4}	0.17	7.34×10^{-6}	0.21	1.00×10^{-5}	1.05	1.32×10^{-4}
Mercury	< 0.0002	$<7.51 \times 10^{-9}$	0.0013	5.61×10^{-8}	0.0018	8.61×10^{-8}	< 0.0002	2.51×10^{-8}
Nickel	0.12	4.51×10^{-6}	< 0.07	$<3.02 \times 10^{-6}$	< 0.05	2.39×10^{-6}	< 0.07	8.01×10^{-6}
Selenium	< 0.002	$<7.51 \times 10^{-8}$	< 0.002	$<8.64 \times 10^{-8}$	< 0.026	1.24×10^{-6}	< 0.005	6.29×10^{-7}
Silver	0.01	$<3.76 \times 10^{-7}$	< 0.01	$<4.32 \times 10^{-7}$	< 0.01	4.79×10^{-7}	< 0.01	1.26×10^{-6}
Zinc	1.4	5.26×10^{-5}	0.05	2.16×10^{-6}	0.06	2.87×10^{-6}	0.25	3.15×10^{-5}

Note: Plant A: 2558 MW, cyclone, fly ash/slag = 30/70
Plant B: 240 MW, pulverized coal, fly ash/slag = 50/50

cause scaling or corrosion problems in process equipment and would result in high concentrations of trace metals in any blow-down from such a system. They believed that some form of treatment of the recycled water would be required.

The primary cause of scale formation is supersaturation (31). When the solubility product of a water-borne mineral in solution is exceeded, it precipitates and may form scale. Secondary causes may be changes in pressure, pH, flow rate or surface geometry. Supersaturated solutions, which contain higher concentrations of dissolved solute than their equilibrium concentration, can occur because sub-microscopic crystals which normally precipitate first have a higher solubility than the larger particles.

A saturated solution is one that retains its equilibrium indefinitely in the presence of the solid it is saturated with. Crystals can dissolve only in unsaturated solutions and they crystallize only from supersaturated solutions. Most types of scale are formed preferentially on the hottest surface in the water system since the solubility of most scale-forming minerals decreases with increasing temperature. For example, the solubility of calcium carbonate at 21.1°C is 50 mg/L and decreases to 44 mg/L at 30°C with constant alkalinity (32). Similar solubility rates are typical for other water minerals but few are as pronounced in their temperature sensitivity as calcium carbonate.

Possible scale forming constituents are shown below (33):

Ca^{+2}	gypsum	$CaSO_4 \cdot 2H_2O$
	anhydrite	$CaSO_4$
	calcite	$CaCO_3$
	dolomite	$CaMg(CO_3)_2$
	tricalcium phosphate	$Ca_3(PO_4)_2$
	monetite	$CaHPO_4$
	hydroxyapatite	$Ca_5(PO_4)_3(OH)$
Mg^{+2}	brucite	$Mg(OH)_2$
	magnesite	$MgCO_3$
	hydromagnesite	$Mg_4(CO_3)_3(OH)_2$
	resquebonite	$MgCO_3 \cdot 3H_2O$
	sepiolite	$2MgO \cdot 3SiO_2 \cdot 2H_2O$
	serpentine	$3MgO \cdot 2SiO_2 \cdot 2H_2O$
SiO_2	amorphous silica	$SiO_2 \cdot 2H_2O$

Other scale-forming constituents include metal oxides, carbonates and hydroxides such as CuO, ZnO and $Fe(OH)_3$.

Phosphate-containing minerals are generally very insoluble; however, because phosphate is present in low concentration in ash waters these minerals do not represent a scaling problem. Magnesium salts are usually more soluble than calcium salts. Thus, the magnesium-containing scalants are usually not a problem in ash systems. The silica in the ash transport waters is not sufficient to cause amorphous silica scales. Temperatures of the ash transport waters are not high enough to form anhydrite. For these reasons, the main scaling minerals which would be anticipated in recirculated ash systems would be gypsum, $CaSO_4 \cdot 2H_2O$, and calcite, $CaCO_3$.

As the temperature of a natural water containing bicarbonate ions is raised, the bicarbonate ion breaks down to form carbon disoxide, carbonate ions and water.

$$2HCO_3^{-1} \rightleftarrows H_2O + CO_2 + CO_3^{-2}$$

This reaction goes to completion at 100°C and, in the presence of calcium, precipitation or scaling occurs due to the production of calcium carbonate which, at 100°C, has a solubility of only 13 mg/L.

The amount of scale produced from a water is affected by the amount of bicarbonate ion present, and this is measured by titration with standard acid and is expressed as alkalinity (mg/L $CaCO_3$). This is measured by the amount of acid needed to reach the phenolphthalein end point (P alkalinity) and the methyl orange end point (M or total alkalinity).

The precipitation kinetics of calcium carbonate and magnesium hydroxide have been summarized by Noblett and Christman (34). They predicted the range of solubility products necessary for $CaCO_3$ precipitation and were able to theoretically predict the precipitation kinetics. In a similar way, they were able to draw conclusions about the precipitation kinetics of $Mg(OH)_2$ and could express this by a chemical reaction equation.

To predict potential scaling problems, the scaling potential of $CaCO_3$ can be calculated using the Langelier or Ryznar Indices. These are based on the equilibrium relationship between Ca^{+2}, CO_2, HCO_3^{-1}, CO_3^{-2} and pH. These relationships indicate the degree of saturation with respect to $CaCO_3$.

As previously mentioned, the solubility of calcium carbonate is influenced by many parameters, including calcium hardness, total alkalinity, temperature, and to a lesser extent total dissolved solids. Using these parameters and applying chemical

equilibrium principles, W.F. Langelier developed the calcium carbonate saturation index (35). He showed that each natural water supply is saturated with calcium carbonate at a certain pH. This he called pHs.

If the value of pHs, which can be determined from charts and nomographs (36) or by calculation, is less than the actual pH of the water (that is pH - pHs is positive), then the water is supersaturated with respect to calcium carbonate and will tend to form scale. If pH - pHs is negative, the water will tend to be aggressive and may corrode metals in the system, particularly if oxygen is present. The larger the number, the more scaling or aggressive the water is.

A water can change from aggressive to scaling by changing just one of the above parameters. For example, consider a water containing 220 mg/L total dissolved solids, calcium hardness of 110 mg/L ($CaCO_3$), M-alkalinity of 100 mg/L ($CaCO_3$) and a pH of 7.9. At 10°C this has a pHs of 8.15 and therefore a Langelier saturation index of -0.25 indicating that it is very mildly aggressive. The same water, heated to 60°C has a pHs of 7.2, and a saturation index of +0.7 and thus has a tendency to scale. This is explained in terms of the thermal breakdown of the bicarbonate ion to carbonate ion referred to earlier.

Increasing the total dissolved solids from 220 to 1 000 mg/L, with pH, M alkalinity and Ca hardness unchanged, gives a pHs of 8.20 and increases the scaling tendency slightly.

Elevation of the pH of a natural water, by the addition of a caustic material or by aeration, generally causes a water to have a greater tendency to scale. This is explained in terms of the production of carbonate ions at the expense of bicarbonate ions either by reaction with hydroxide ions

$$HCO_3^{-1} + OH^{-1} \rightleftarrows H_2O + CO_3^{-2}$$

or by removal of carbon dioxide

$$2HCO_3^{-1} \rightleftarrows H_2O + CO_3^{-2} + CO_2$$

An alternative to the Langelier Index is the Ryznar Stability Index (10). This is defined as the empirical relationship 2pHs - pH, and as such is always positive. Values around 7 indicate a stable water, whereas below 6 indicates scaling and above 8 is corrosive.

More recently, based on actual practice, it has been found that the pH of the system can be allowed to go to pHs +1.0 because a certain degree of supersaturation must

be achieved for precipitation to occur. A method of measuring the critical pH of scaling has been described (37). This is based on an experimental determination of the critical pH (pH_c) above which precipitation occurs. This is carried out by incremental addition of sodium hydroxide until precipitation occurs in the bulk liquid and the pH drops. The addition of sodium chloride has little effect on pH_c whereas the addition of Mg^{+2} or SO_4^{-4} has an appreciable effect (38).

An early approach to calcium carbonate scale control was the acidification of the makeup water using sulphuric acid. This reduces the alkalinity and converts most of the calcium bicarbonate to calcium sulphate, which has a much higher solubility than calcium carbonate (approximately 1 700 mg/L in waters at normal temperatures, compared with about 30 mg/L or less for calcium carbonate). Care, however, must be taken to avoid scaling by what is probably the second most common scalant, calcium sulphate. Calcium sulphate is a problem in flood operations and evaporative desalination.

The solubility limit of $CaSO_4$ is governed by its solubility product. Other factors influencing its solubility to some extent include the effect of time, temperature, pressure and added salts, both common ion and others. These have been reviewed in detail (31).

Calcium sulphate, below 42°C, is predominantly present as gypsum, $CaSO_4 \cdot 2H_2O$. Between 42°C and 98°C, it is present as anhydrite, $CaSO_4$. Rule of thumb solubility products for this scaling mineral in waters where the dissolved solids or ionic strengths are moderate tend to give conservative estimates of scaling potential.

The solubility of calcium sulphate at less than 100°C is generally governed by the temperature, by the concentration of calcium ions, and by the concentration of sulphate ions. Calcium sulphate solubility increases up to about 30 to 40°C reaching a maximum of about 1 550 mg/L (as $CaCO_3$) and then falls off to about 1 250 mg/L (as $CaCO_3$) at 100°C. At higher temperatures and pressures, the solubility decreases quite dramatically, and at 170°C and 690 kPa it is only 103 mg/L (as $CaCO_3$).

Based on the principles of scale formation, Nelson (39) developed the following limitations for recirculating water quality. These limitations can be used to assess the likelihood of a recirculated water scaling. For example, a water containing 1 310 mg/L of calcium and 1 390 mg/L of sulphate has a product of 1 820 900 which is much greater than the limitation of 500 000. Based on Nelson's work, it can be concluded that a calcium sulphate scaling problem would exist. These limitations are based upon the concentrations of the cation and anion species and do not consider the presence of other ionic species in

Characteristic	Limitation	Comment
pH and hardness	Langelier Saturation index = 1.0 Ryznar Stability index = 6.0 to 7.0	LSI = pH-pHs
Sulphate and calcium	$(C_{SO_4}) \times (C_{Ca}) = 500\ 000$	C_{SO_4} = concentration SO_4^{-2} (mg/L) C_{Ca} = concentration Ca^{+2} (mg/L)
Calcium phosphate	$(C_{Ca})^3 \times (C_{PO_4})_2 = 0.06$	C_{Ca} = concentration Ca^{+2} (mg/L) C_{PO_4} = concentration PO_4^{-3} (mg/L)
Silica	$C_{SiO_2} = 150$	concentration in mg/L
Magnesium as Silica	$(C_{Mg}) \times (C_{SiO_2}) = 35\ 000$	in mg/L
Suspended solids	$C_{ss} = 400$	in mg/L

the water. To more accurately predict the scaling potential of a recirculated water, other researchers have studied this approach and have attempted to modify it to reflect the conditions in operating systems.

Denman (40) discussed the maximum reuse of cooling water based on the solubility and content of gypsum ($CaSO_4 \cdot 2H_2O$) in the actual system. This approach may be applied to maximize the reuse of bottom ash waters if calcium sulphate is a potential scale-forming mineral in the system. Due to common ion salts such as Na_2SO_4 and $MgSO_4$, and ion salts such as NaCl, there can be ionic interaction. This may influence the solubility of gypsum and any scheme for predicting gypsum solubility. Results of his work showed that the values of the products are considerably greater than 500 000 by a factor of 1.5 for pure gypsum solubility at 45°C, and a factor greater than 1.5 with salts present.

Noblett and Christman (34) showed that the carbon dioxide mass transfer between the pond liquor and the atmosphere will affect the $CaCO_3$ and $Mg(OH)_2$ scale potential in a fly ash system. In a recirculating ash sluice system, there is a potential for CO_2 transfer between the atmosphere and the pond water. The degree of CO_2 transfer will effect the pH of the pond return water. Since both $CaCO_3$ and $Mg(OH)_2$ relative

saturations are pH dependent and tend to precipitate at higher pH, the degree of CO_2 transfer will have an effect on the scaling tendency with respect to these two species.

Increased CO_2 sorption in the pond will increase the $CaCO_3$ scale potential and decrease $Mg(OH)_2$ scale potential. Since these scales are pH dependent, greater problems may be encountered with very alkaline ashes. These scales are softer than gypsum scale and may be eroded by the ash.

The relative solubility (RS) of a species is the ratio of the amount of a species present in a liquid to the theoretical maximum solubility under the same conditions. When the RS of a species is below 1.0, no potential for scale formation exists. When the RS is greater than 1.0, a potential for solids formation exists but scale will not necessarily form. When the RS of a species is above a critical value, nucleation and scale formation are likely. The critical value of $CaSO_4 \cdot 2H_2O$ is 1.3 to 1.4, for $CaCO_3$, 2.5, and $Mg(OH)_2$, 3.4. Samples taken from existing once-through ash sluicing operations have shown $CaCO_3$ RS values as high as 38.8 without scaling problems. This suggests that the solubility of a species cannot be used to predict whether a scaling problem can exist in a recirculating system.

In a summary article, Zalogin and Shekanov (41) discuss hydraulic ash removal systems and the related water chemistry problems. Soviet power stations were grouped according to the fuel type, ash collection system and the composition of clarified water in the ash system. The dependence of the solubility of some compounds in clarified water from ash lagoons and the time required to achieve an equilibrium concentration of $Ca(OH)_2$ was shown. In covered ash water reservoirs where there is no contact with the atmosphere, calcium hydroxide alone precipitates from the water. Only limited precipitation of calcium carbonate is apparent. The authors described a closed hydraulic ash removal system which was arranged to prevent scaling in pipe and pump systems. Supersaturation of clarified water with calcium hydroxide can be eliminated by holding the water in an ash lagoon reservoir for a sufficiently long time. To prevent supersaturation of the water with $CaCO_3$, the water flows through a baffled channel. These baffles stop the flow of the upper layers of water. On the stationary water surface, according to experience, a floating film of $CaCO_3$ forms, preventing carbon dioxide from penetrating the surface of the alkaline clarified water. Crystallization of calcium carbonate from the supersaturated water takes place on the surface of these crystals and on the baffles, walls and bottom of the return channel. To increase the area of the crystallization surface further, metal grids are submerged in the channel. Both calcium hydroxide and calcium carbonate can precipitate on the grids when the clarified water is

supersaturated with calcium hydroxide. The authors suggest that the components and their layout can affect the location and amount of scaling in a recirculating system.

Although researchers have attempted to improve the techniques of predicting the formation of scale, a large number of factors still have not been incorporated into these scale predicting procedures. For this reason, the site-specific performance of operating recirculating systems must be studied to gain a more complete understanding of the scale formation process in bottom ash systems.

Researchers have also considered several methods to treat the recirculating ash transport water to reduce its scaling potential. These treatment approaches include chemical softening, membranes, and ion exchange. A more detailed discussion of blowdown treatment is presented in Section 6.

3.5.3 Mechanical Problems. Bottom ash particles are very abrasive. In the design of bottom ash removal systems, special abrasion-resistent metal alloys are used for components and fittings. Greatest wear occurs when the ash slurry changes direction such as in valves or elbows. The problem of abrasion is most pronounced in the ash transport system from the bottom ash hopper to the ash settling equipment. When the bottom ash has settled, the concentration of suspended bottom ash particles which would cause mechanical erosion is greatly reduced. Consequently, the likelihood of abrasion occurring in the return lines to the bottom ash hopper is small.

Other possible mechanical problems include:

- freezing of lines, hydrobins and valves in winter conditions;
- improper design of ash transport system resulting in under-sized lines which plug with ash or oversize lines in which adequate sluice velocities cannot be maintained;
- improper sizing of ash dewatering lines;
- specification of improper ash sluice pumps;
- improper location of ash sluice and recirculated water lines.

3.6 Summary

Three factors can control the degree of recirculation of bottom ash transport water systems. These are hydraulic loading, accumulation of chemical constituents and mechanical problems. Some generating stations have been operating completely closed bottom ash transport systems without serious problems. This suggests that apparent theoretical limitations are either not significant or can be overcome by proper design and operation of the system.

4.0 CASE HISTORIES OF BOTTOM ASH TRANSPORT WATER RECYCLE AND REUSE

Site visits were made to observe actual recirculating ash water systems in operation and to assess the feasibility of fully-closed bottom ash transport systems. The sites represented a wide range of bottom ash handling systems. Characteristics considered in the selection of generating stations to be visited included:

- station location, generating capacity and history,
- coal source, ash content and consumption rates,
- type of bottom ash settling system (hydrobin or lagoon system),
- separate or combined fly and bottom ash disposal system,
- applicability of data to Canadian operating conditions.

The stations are listed in Table 15. In addition to these plants, several stations are also included which were not visited but provide a broader baseline of information for consideration of recirculating bottom ash systems.

TABLE 15 SUMMARY OF CASE HISTORIES

Generating Station	Location	Nominal Generating Capacity (MW)	Coal	Type of Bottom Ash Handling System
Dunkirk	New York	610	Eastern	Recirculating
Sherburne County	Minnesota	1 360	Western	Recirculating
Nanticoke	Ontario	4 000	Eastern	Recirculating
Sundance	Alberta	1 350	Western	Recirculating
Dalhousie	New Brunswick	322	Eastern	Recirculating
Lingan	Nova Scotia	300	Eastern	Recirculating
Boundary Dam	Saskatchewan	882	Western	Once-through
Bruce Mansfield	Pennsylvania	1 700	Eastern	Recirculating
Milliken	New York	270	Eastern	Recirculating
Centralia	Washington	1 400	Western	Recirculating
Hayden	Colorado	460	Western	Recirculating
Four Corners	Arizona	2 150	Western	Recirculating

4.1 Dunkirk Generating Station

4.1.1 Plant Description. The Dunkirk Generating Station, located in Dunkirk, New York, is owned and operated by Niagara Mohawk Power Corporation, Syracuse, New York. This plant, located on Lake Erie, has a nominal generating capacity of 610 MW. In 1950, units 1 and 2 were built, each with a capacity of 95 MW. Later in 1960, unit 3 rated at 190 MW, and unit 4 rated at 205 MW, were added. The continuously recycling bottom ash water system, which was required to comply with U.S. Environmental Protection Agency regulations, was designed and installed in 1972. The closed system has been operating since that time on all four units.

4.1.2 Ash Handling System. Bituminous coal from Pennsylvania is burned at the station. It is delivered sized to 5 cm diameter and is characterized below.

Parameter	Typical Value
Fixed carbon (%)	53
Ash (%)	12
Sulphur (%)	2.1
KJ/kg	29 530

The daily consumption is 4 536 tonnes at a generating capacity of 610 MW. The boiler is a Combustion Engineering wet bottom unit using pulverized coal firing. Compressed air is used for slag breaking. There are a total of six ash hoppers for all units, one each for unit numbers 1 and 2 and two each for units 3 and 4. Each hopper is equipped with six nozzles to direct bottom ash down into the hopper. Water for this purpose is supplied by two flushing pumps in series.

Fly ash is collected using electro-static precipitation and is transported to a storage silo by a dry system. This ash is removed from the site by truck by a private contractor for disposal as landfill.

The bottom ash water recycle system was designed for a coal with a maximum ash content of 15 percent with 30 percent of this ash present as bottom ash. The removal rate was expected to be 127.40 m^3 per eight hours. The major equipment in the system is as follows:

Hydrobins - Two identical hydrobins 10.67 m in diameter with a storage capacity of 806.84 m^3 are located outside the main station building. The bins are capable of storing three days bottom ash production at full station load. A stainless steel screened overflow

weir and carbon steel underflow baffle are installed in each bin. All material entering the bin must pass under this baffle before reaching the screened overflow weir and overflow trough which extends around the periphery at the tank top.

Water is decanted from the ash in the hydrobins and passes to the settling tank. Ash is discharged from the bottom of the bins through a hydraulic slide gate. This gate is manually controlled by an operator at the truck loading station. Bottom ash is removed from the station by truck by a private contractor and contains 20 percent moisture. The bottom ash is disposed of in a landfill site.

Settling Tank - Water decanted from the ash in the hydrobins is fed to the centre of the settling tank. In the 15.25-m diameter, 510-m^3 conically shaped tank, residual solids are further removed. Accumulated sludge is continuously pumped from the tank bottom to the hydrobins.

Recirculation Tank - Water from the settling tank enters the recirculation tank at the top. The tank itself is 16.76 m in diameter with a capacity of 1 530 m^3. Sludge from the settled ash is pumped by sludge pump from the recirculation tank to the hydrobin. Nozzles were originally used to direct the accumulated sludge down the conical walls of the recirculation and settling tanks. However, these failed early in the unit's life and were never replaced. Once per year this tank is shut down and the tank is cleaned out to remove any accumulated solids.

The suction for the pumps used for sluicing and flushing ash is located in the recirculation tank 2.5 m above the bottom of the tank.

The ash recycle system was originally designed to remove pyrite rejects from the coal mills. These were to be sluiced to the hydrobins. The reject particles from the mills were too large to be carried in the 15.25-cm diameter slurry line without line plugging. Currently, the rejects drop onto the station floor where they are removed with a front end loader.

4.1.3 Water Balance. Prior to the start up of the recirculating system in 1972, the bottom ash was sluiced from the boiler ash pits to three ash ponds located at the west end of the station boundary. The ash settled out in these ponds and the effluent water overflowed through a collecting chamber directly to the harbour. Water for sluicing and line purging was taken from the station service water supply.

The current water uses in the bottom ash system for this station are shown in Figure 13. The water uses do not balance but do illustrate where water is used in the

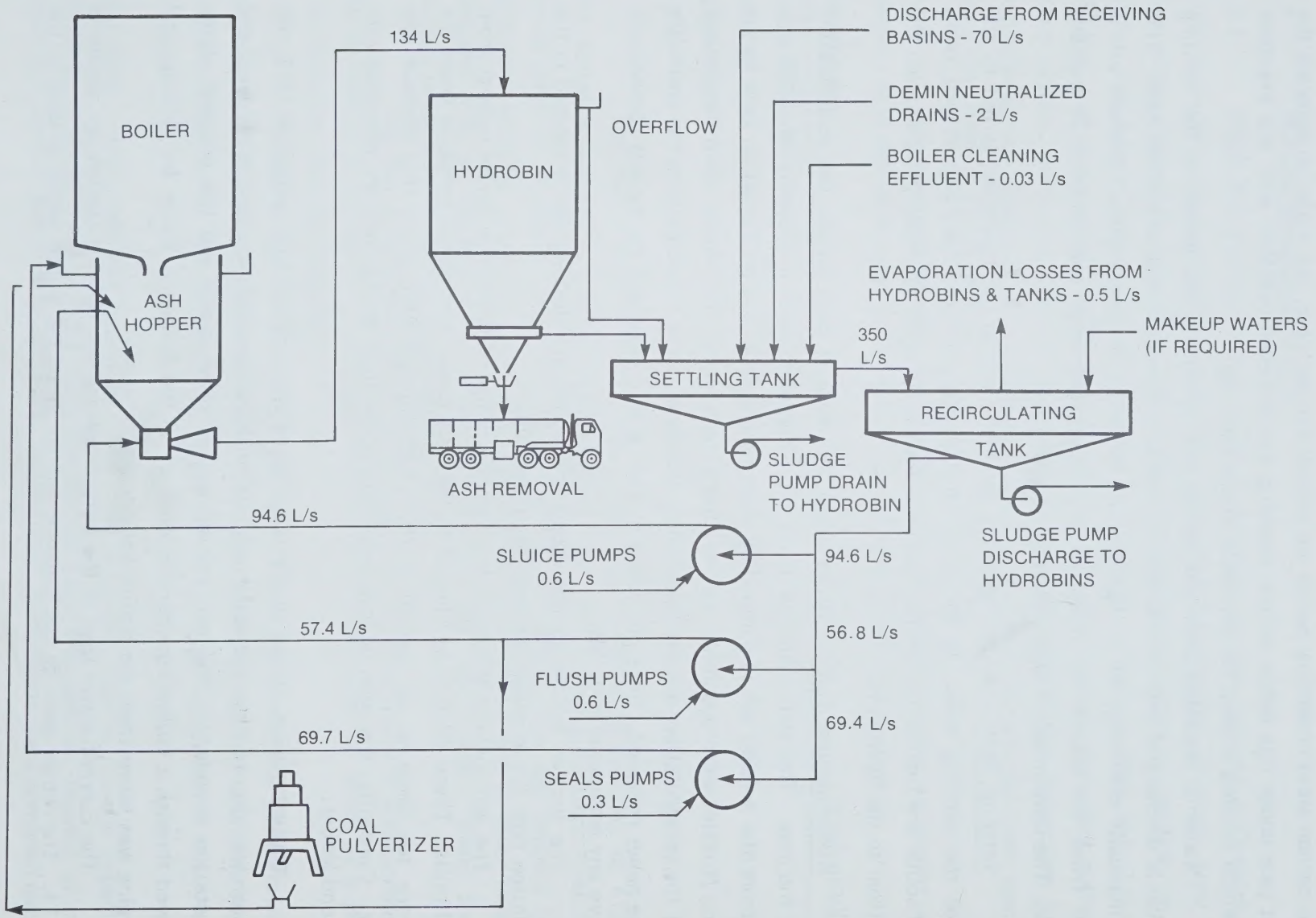


FIGURE 13 DUNKIRK GENERATING STATION BOTTOM ASH SYSTEM WATER BALANCE (13)

system and the relative magnitudes of the flows. Instantaneous flow rates are cited for noncontinuous flows. The daily water consumption depends on the duration of each operation. Bottom ash is sluiced from each hopper at eight-hour intervals using a 10 percent solids in water ash slurry. The total sluicing and line purging time per day is 10 to 12 hours depending on the individual operator. The water flow rate for sluicing is 94.6 L/s. Under normal conditions, only one hopper is sluiced at a time, but there is the capability to sluice two hoppers simultaneously.

The flushing pumps are operated in series to provide 56.8 L/s at 1 045 kPa head for each flushing cycle. Two pumps, similarly connected, serve as standby. Sluicing pumps operate in series to provide 97.8 L/s at 1 732 kPa head. Two pumps are similarly connected and serve as a standby system. One seal water pump with a capacity of 69 L/s is operated while one is maintained as a standby. The seal water requirement for the sluice, flush and seals pumps is 1.6 L/s.

Bottom ash is discharged to the hydrobins which are outside but adjacent to the main powerhouse. Eight to ten hours is required for the ash to settle from the transport water. This bottom ash system receives wastewater from receiving basins around the station, demineralizer wastes and boiler cleaning effluents. This volume is approximately 72 L/s or about 20 percent of the total discharge from the settling tank.

Evaporation from the recirculating tank is 0.5 L/s. Water occluded with the bottom ash, based on a 20 percent moisture content, is lost at 0.7 L/s. These two water losses represent about 2.5 percent of the recirculated water volume.

Make-up water can be added to the recirculating tank on an 'as required' basis. There is also a provision for an emergency overflow from the system. This water can be treated using sand filters and reused in the station or discharged to Lake Erie. Routine operation of the system does not require a discharge. This system serves as an emergency back-up should it ever be required.

Under normal operating conditions the system operates without direct discharge or intentional blowdown. The losses due to evaporation and in the wet ash balance the make-up resulting from the discharge of other wastewater streams to the system.

4.1.4 Water Chemistry. The pH and turbidity of the recirculating water in the system is monitored to detect any significant change in quality. The pH meter is located at the settling tank and the turbidity meter is located on the suction header of the ash water supply lines.

Typical recirculated water quality is:

pH	8.0 - 8.5
Conductivity	490 - 660 µmhos
Total suspended solids (average)	37 - 57 mg/L
Total suspended solids (maximum)	200 mg/L

There has been no evidence of scale buildup or corrosion anywhere in the ash water recycle system. The conductivity of the sluice water is much lower than that reported at other stations. Based on data for this station there is no explanation for this low value. The main concern has been mechanical erosion and abrasion of nozzles, valves and fittings where the ash slurry changes direction. The system was described by operating personnel as a high maintenance system, that, when operated by manual controls, worked acceptably well.

4.1.5 Mechanical Problems. All sluice lines from the ash hoppers in the plant are located in the sub-basement. Outside, lines run both above and below ground. After severe winter conditions caused vertical lines to the hydrobins to freeze up, all outside lines were heat traced and insulated. Sluice water lines are self-draining in the system. The sluice lines to the hydrobins are also equipped with drains which are opened after the sluicing cycle. The pipe itself is hardened nickel alloy steel. To achieve a service life of five years, pipes should be rotated about every six months. However, this is not done on a routine basis.

The original capital cost of the system in 1972 was 1.2 million U.S. dollars. The system was designed to operate automatically; however, problems were encountered with the control systems. The system now functions on a manual cycle.

4.1.6 Summary. The bottom ash transport system at the Dunkirk Generating Station operates with a zero discharge of chemical constituents and transport water. An emergency back-up system exists at the station to treat excess water from the system should a blowdown ever be required. This back-up system is not routinely used at this plant.

Figure 14 shows the generalized water balance for the system. Water losses in the system due to occlusion with the bottom ash and as evaporation are made up to maintain the water balance in the system. This make-up water represents about two percent of the recirculated water flow.

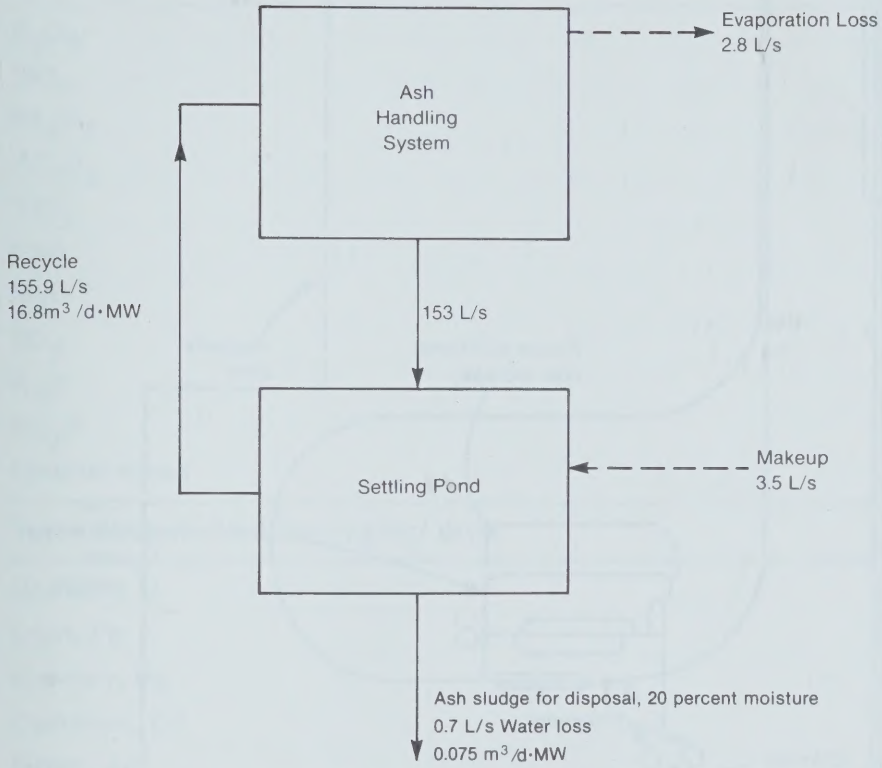


FIGURE 14 WATER LOSSES IN RECYCLE SYSTEM - DUNKIRK GENERATING STATION (29)

4.2 Sherburne County Generating Plant

4.2.1 Plant Description. Northern States Power Company, which serves the Minnesota - Dakotas area, owns and operates the Sherburne County Generating Plant. The plant consists of two 680-MW units for a total nominal generating capacity of 1 360 MW and is located in Becker Township, Sherburne County, Minnesota, southwest of the Village of Becker, 64 km northwest of Minneapolis. The site plan for the generating plant is shown in Figure 15.

4.2.2 Ash Handling System. The primary fuel is sub-bituminous coal from the Colstrip area of Montana. The analysis of the resultant ash from the combustion of this coal is presented in Table 16.

Based on data collected for a 50-week period ending in 1978, the average daily bottom ash production was 353.80 tonnes with 24 percent of the coal ash present as bottom ash. With an average bulk density of 1 169.35 kg/m ^{3}, the average daily rate of bottom ash production for the year was 263.71 m ^{3} at 1 100 MW gross load.

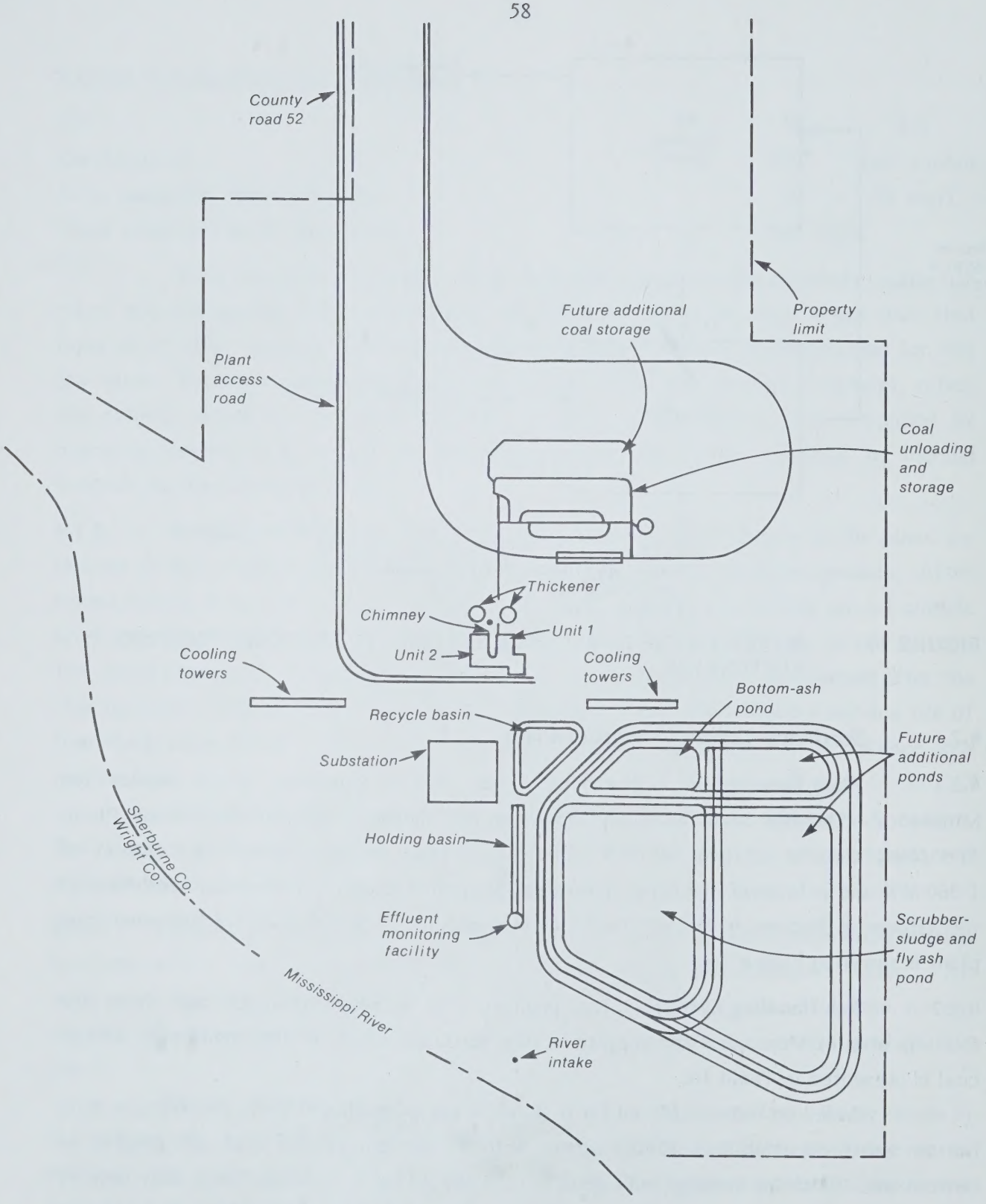


FIGURE 15 SHERBURNE COUNTY GENERATING PLANT SITE PLAN

TABLE 16 COAL ASH ANALYSES - SHERBURNE COUNTY GENERATING PLANT

Standard of Mineral Analyses of Ash (Percent)	
P_2O_5	0.5
SiO_2	35.3
Fe_2O_3	6.9
Al_2O_3	17.2
TiO_2	0.7
CaO	17.4
MgO	4.3
SO_3	15.2
K_2O	0.4
Na_2O	1.5
Undetermined	0.6
Trace Element Analyses (mg/kg/ dry)	
Uranium, U	1.9
Lead, Pb	5.1
Mercury, Hg	0.13
Cadmium, Cd	0.10
Silver, Ag	0.06
Molybdenum, Mo	2.3
Selenium, Se	1.2
Arsenic, As	2.2
Germanium, Ge	2.1
Zinc, Zn	14
Copper, C	9.2
Nickel, Ni	10
Manganese, Mn	102
Chromium, Cr	5.1
Vanadium, V	7.8
Fluorine, F	60
Boron, B	31
Beryllium, Be	0.88
Chlorine, Cl	845
Antimony, Sb	0.85
Barium, Ba	310
Radioactivity Analyses (pCi/g dry)	
Ash Sample	
Gross Alpha	13
Gross Beta	22
Total Gamma	26

The furnaces are tangentially-fired using pulverized coal. Each steam generator is equipped with a wet flue gas scrubber for air pollution control. These units also capture fly ash produced during combustion.

The bottom ash sluicing system was originally designed to be continuously operated in an automatic mode. Currently, the system is run manually with sluicing once per shift or once per day. The ash water slurry is pumped to a lagoon where the bottom ash settles and the water is recirculated. Pyrites and other rejects from the coal mills are conveyed to the bottom ash hopper and are disposed of with the bottom ash.

Both bottom and fly ash are ultimately disposed of on-site in separate lagoons. A schematic of the lagoon system is shown in Figure 16.

The ash transport lines from the plant are sloped down toward the basin and powerhouse with drains provided at low points. Drained water from the lines flows to the recycle basin. Freezing in the lines is prevented by the use of motor-driven valves which isolate the lines when dry. All valves are contained in heated houses to prevent a repetition of previous winter freezing problems. The transport lines run to the 7.28-ha, 7.57×10^5-m^3 capacity bottom ash disposal basin. An above-water discharge is used for the slurry. Water from the ash pond flows via a sluice gate to the recycle basin which has a 3-ha area and 1.06×10^6 m^3 capacity.

Once the existing basins are filled, new containment facilities will be built on the plant site. Bottom ash from the station, which dewaters very well in the lagoon, is periodically removed by an outside contractor. It is being used as class 5 aggregate or as a supplement in light-weight concrete products. At the plant, bottom ash is used for roadways and as a coal storage pile lining.

Ash sluice lines are above ground and are designed to be self-draining to prevent freeze up in winter. Return lines are buried underground. Pipes inside the plant are made of hard casing steel. Outside sluice lines of high nickel alloy steel are rotated to extend their service life. Laterals and bends erode quickly; however, these are being replaced with reinforced fittings.

4.2.3 Water Balance. The water handling system for the Sherburne County Generating Plant is shown in Figure 17. High pressure water is supplied to the bottom ash system from the recycle basin by reclaim water pumps at 211 L/s. From this supply, make-up to the bottom ash hopper requires 17.7 L/s, refractory cooling needs 53 L/s, and 12.9 L/s is used for seals.

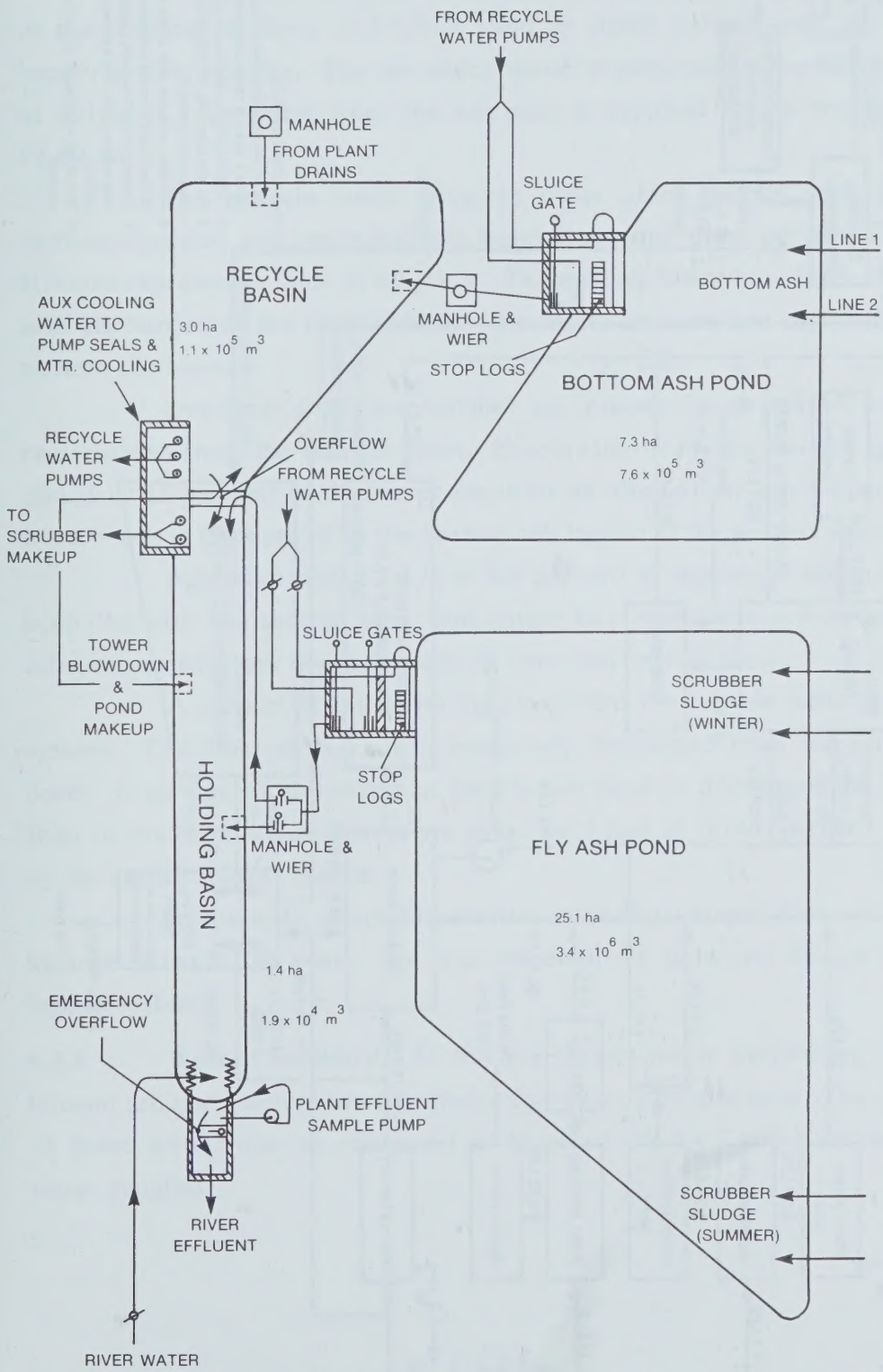
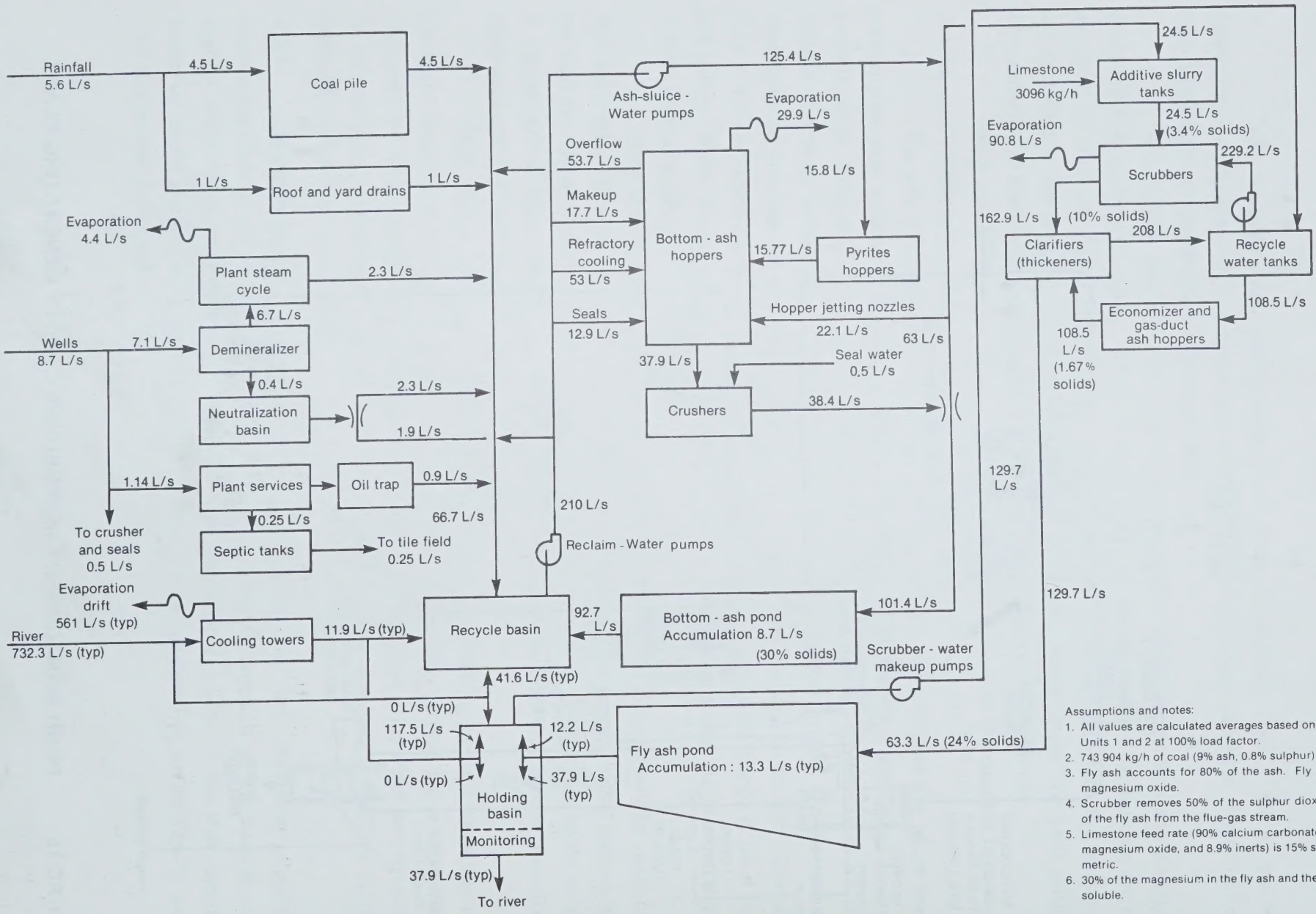


FIGURE 16 POND MANAGEMENT - SHERBURNE COUNTY GENERATING PLANT



Assumptions and notes:

1. All values are calculated averages based on operation of Units 1 and 2 at 100% load factor.
2. 743 904 kg/h of coal (9% ash, 0.8% sulphur) is burned
3. Fly ash accounts for 80% of the ash. Fly ash is 5.36% magnesium oxide.
4. Scrubber removes 50% of the sulphur dioxide and 99% of the fly ash from the flue-gas stream.
5. Limestone feed rate (90% calcium carbonate, 1.1% magnesium oxide, and 8.9% inerts) is 15% stoichiometric.
6. 30% of the magnesium in the fly ash and the limestone is soluble.

FIGURE 17 SHERBURNE COUNTY GENERATING PLANT WASTEWATER DISPOSAL SYSTEM

The bottom ash sluice water pumps supply 125.4 L/s. Of this, 24.5 L/s is used in the scrubber system, 15.8 L/s is used to sluice pyrites, and 22.1 L/s is required for hopper jetting nozzles. The ash sluice water is returned to the bottom ash pond at a rate of 101.4 L/s. Overflow from the ash pond is supplied to the recycle pond at a rate of 92.8 L/s.

The recycle basin receives other plant wastes such as coal pile runoff, demineralization and neutralization basin flows and plant service waters. These waste streams represent a flow of 69.7 L/s. The cooling tower blowdown of typically 11.9 L/s is also discharged to the recycle basin. No waste streams are disposed of directly into the bottom ash lagoon.

Overflow from the bottom ash hopper comprises 44 percent of the water recirculated from the recycle basin. Evaporation from the bottom ash hopper represents 30 L/s or 16 percent of the water required for the bottom ash hopper and sluicing system. Bottom ash is disposed of in the bottom ash lagoon at 30 percent solids.

Approximately 8.7 L/s or 8.6 percent of the water which flows to the lagoon is occluded with the bottom ash. This water loss represents a blowdown from the bottom ash transport system which is made up from the recycle basin.

A portion of the water supplied from the recycle basin is used in the scrubber system. This flow of 24.5 L/s is eventually discharged from the scrubbers to the fly ash pond. A portion of the water in the fly ash pond is discharged to the holding pond and then to the river. This represents an indirect loss of three percent of the water supplied by the reclaim water pumps.

In the area where this station is located, evaporation and precipitation roughly balance through the year. For this reason there is no net loss or gain of water in the lagoon system.

4.2.4 Water Chemistry. At the Sherburne County Generating plant both the fly and bottom ash pond waters are monitored for various parameters. The chemical consitutents of these waters can be compared to those of the well and river water used as the raw water supplies.

Constituent	Concentration (mg/L) Well	River
Calcium (Ca)	48.0	40.1
Magnesium (Mg)	10.7	15.6
Sodium (Na)	2.7	4.8
Sulphate SO_4)	11.0	10.0
Chlorine (Cl)	1.9	3.6
Nitrate (NO_3)	3.0	1.9
Bicarbonate (HCO_3)	172.0	181.0
Silicon Dioxide (SiO_2)	9.8	5.8

Analyses of bottom ash pond waters from January 1977 through December 1978 are presented in Tables 17 to 20.

The calcium levels and pH of the bottom ash water appear to have stabilized at around 675 mg/L and 8.5, respectively. The magnesium concentration is now around 1 200 mg/L although there are some fluctuations. The recent upward change in levels is likely due to a change in coal burned at the station.

Total dissolved solids levels have increased steadily since 1977 from around 2 000 to 9 000 mg/L. During the same period the magnesium levels have increased and have levelled off at 1 200 mg/L.

These analyses indicate the changes that can be expected with recycling of the bottom ash transport water. The changes in the water quality following the start up of the system are particularly evident.

There was a general feeling that a potential scaling or precipitation problem existed but there has been no evidence of this in the system to date.

4.2.5 Mechanical Problems. Bottom ash, by design, was to be transported at a rate of 92.5 tonnes per hour, at 242.9 L/s with a velocity of about 3 m/s. The actual sluicing rate is 27.2 tonnes per hour. In the opinion of the station personnel, one factor appears to have caused the variation from the design. Sluice pipes were oversized for the design flows. The sluice velocity is not sufficiently high. This permits the ash to settle out in the line and cause plugging. Longer sluice times are required when the lines fill with ash. Additional purging is now required to thoroughly clean out the transport lines.

TABLE 17 ANALYSES OF BOTTOM ASH POND WATER - JANUARY TO JUNE, 1977 - SHERBURNE COUNTY GENERATING PLANT

Analysis	Maximum	Minimum	Mean	Std. Dev.
Solids				
Dissolved Solids (mg/L)	7 670	2 304	5 101	1 348
Suspended Solids (mg/L)	30.2	8.7	16.2	5.9
Cation				
Calcium (mg/L Ca)	672	310	574	88
Magnesium (mg/L Mg)	712	104.5	417.7	148.2
Sodium (mg/L Na)	78	72.5	75.3	3.89
Anion				
P-Alkalinity (mg/L $CaCO_3$)	75	0	35	23.5
M-Alkalinity (mg/L $CaCO_3$)	177	62	133.6	29.8
Carbonate (mg/L CO_3)	84	0	42	28.2
Bicarbonate (mg/L HCO_3)	137.7	22	76.5	38.2
Hydroxide (mg/L OH)	0	0	0	0
Sulphate (mg/L as S)	816	715	766	71.4
Chloride (mg/L Cl)	74	64	69	7.1
Nitrate (mg/L as N)	9.7	8	8.85	1.2
Miscellaneous				
pH	9.1	7.8	8.65	0.31
Spec. Cond. (µmho/cm)	3 660	3 660	3 660	0

The greatest problem with the ash sluicing system was with the recycle pump, pump seals and pump rotating parts. These problems were not totally attributed to the recirculating transport water system but could be, in part, explained by the use of improper equipment in the system. Generally, high wear was evident in valves or any place where the ash sluice changed direction. This problem was confined to the ash discharge side of the system. Other wear problems included the flushing nozzles in the boiler bottom. Vibration caused these nozzles to break off. Steel header lines are being replaced with rubber ones to eliminate this problem.

TABLE 18 ANALYSES OF BOTTOM ASH POND WATER - JULY TO DECEMBER 1977 - SHERBURNE COUNTY GENERATING PLANT

Analysis	Maximum	Minimum	Mean	Std. Dev.
Solids				
Dissolved Solids (mg/L)	9 245	4 336	6 955	1 559
Suspended Solids (mg/L)	35.8	5.8	17.36	8.45
Cation				
Calcium (mg/L Ca)	743	585	668.8	38.6
Magnesium (mg/L Mg)	1 095	272.0	704.7	276.6
Sodium (mg/L Na)	155	73.0	122.7	26.9
Anion				
P-Alkalinity (mg/L $CaCO_3$)	67	16	42.8	13.3
M-Alkalinity (mg/L $CaCO_3$)	272	117	199.3	56.1
Carbonate (mg/L CO_3)	92	19.2	54.0	18.4
Bicarbonate (mg/L HCO_3)	293	39	138	78.6
Hydroxide (mg/L OH)	0	0	0	0
Sulphate (mg/L as S)	1 957	698	1 295	368.7
Chloride (mg/L Cl)	160	54	103.6	32.5
Nitrate (mg/L as N)	15.0	4.5	10.91	2.76
Miscellaneous				
pH	8.9	8.4	8.61	0.13
Spec. Cond. (µmho/cm)	6 270	3 030	4 616	880

4.2.6 Summary. At the time the site visit was made, the start-up and commissioning problems normally encountered with a new generating station had just been rectified. Representative operating experience was limited to less than a year.

The bottom ash transport system at this station is operated without a direct blowdown; however, the ash transport system is integrated with the wastewater disposal system for the whole plant. The overflow from the bottom ash lagoon is mixed with other wastewaters in the recycle basin. A portion of the water supplied from this basin is

TABLE 19 ANALYSES OF BOTTOM ASH POND WATER - JANUARY TO JUNE, 1978 SHERBURNE COUNTY GENERATING PLANT

Analysis	Maximum	Minimum	Mean	Std. Dev.
Solids				
Dissolved Solids (mg/L)	9 275	6 480	7 772	870
Suspended Solids (mg/L)	42.6	16.8	27.8	6.9
Cation				
Calcium (mg/L Ca)	724	615	668	31
Magnesium (mg/L Mg)	1 013	686	852	92
Sodium (mg/L Na)	188	68.8	150	26.6
Anion				
P-Alkalinity (mg/L $CaCO_3$)	64	0	27.3	17.8
M-Alkalinity (mg/L $CaCO_3$)	298	200	233	27.1
Carbonate (mg/L CO_3)	76.8	0	32.8	21.3
Bicarbonate (mg/L HCO_3)	344	132	222	57.6
Hydroxide (mg/L OH)	0	0	0	0
Sulphate (mg/L as S)	1 671	1 237	1 414	128.5
Chloride (mg/L Cl)	170	84	116	18.2
Nitrate (mg/L as N)	17.8	5.7	11.8	3.4
Miscellaneous				
pH	8.7	8.3	8.47	0.12
Spec. Cond. (µmho/cm)	6 190	4 100	5 037	604

supplied to the scrubber system and is discharged to the fly ash pond. This loss represents about three percent of the water supplied to the bottom ash transport system. The bottom ash transport system at this plant operates as a closed system with three percent blowdown resulting from the integration of the scrubber system in the bottom ash recycle system. Makeup is supplied from station raw water supplies. No scaling was evident in any part of the recirculation system.

TABLE 20 ANALYSES OF BOTTOM ASH POND WATER JUNE TO DECEMBER, 1978 SHERBURNE COUNTY GENERATING PLANT

Analysis	Maximum	Minimum	Mean	Std. Dev.
Solids				
Dissolved Solids (mg/L)	12 690	5 345	9 013	1 942
Suspended Solids (mg/L)	128.6	16	43.8	30.6
Cation				
Calcium (mg/L Ca)	712	635	667	22.2
Magnesium (mg/L Mg)	1 563	574	1 048	332
Sodium (mg/L Na)	210	140	170	24.1
Anion				
P-Alkalinity (mg/L $CaCO_3$)	32	0	7.7	10.6
M-Alkalinity (mg/L $CaCO_3$)	370	181	266	142
Carbonate (mg/L CO_3)	38.4	0	9.2	12.7
Bicarbonate (mg/L HCO_3)	451	163	278	93.6
Hydroxide (mg/L OH)	0	0	0	0
Sulphate (mg/L as S)	2 345	1 036	1 672	383
Chloride (mg/L Cl)	190	93	136	30.7
Nitrate (mg/L as N)	22.0	5.5	11.4	4.7
Miscellaneous				
pH	8.5	8.1	8.35	0.13
Spec. Cond. (µmho/cm)	8 370	4 650	6 268	973

4.3 Nanticoke Generation Station

4.3.1 Plant Description. The Nanticoke Generating Station is located near Nanticoke, Ontario, about 60 km southwest of Hamilton. The station, which is located on Lake Erie, has eight 500-MW units which were commissioned between 1972 and 1977.

4.3.2 Ash Handling System. A blend of bituminous coals from Pennsylvania and western Canada is burned at the station. Typical coal analysis and consumption rates are shown below:

	U.S. (Pennsylvania) Bituminous		Western Canada (B.C.) Bituminous	
	Average	Range	Average	Range
Ash content (%)	9.3	7.1 - 9.3	13.5	11.1 - 15.8
Moisture (%)	5.3	4.4 - 6.5	7.3	5.2 - 10.2
Heat Value	30 500 kJ/kg		30 020 kJ/kg	
Annual Consumption	4.4×10^6 tonnes		2.5×10^6 tonnes	

The maximum daily consumption of coal is 3.8×10^4 tonnes using a 50/50 blend of U.S. and Western Canadian coals. The average daily coal consumption for the same blend is 1.89×10^4 tonnes.

Combustion of a typical blend of coal produces a bottom ash with the following characteristics:

Component	(g/kg)
SiO_2	456
Al_2O_3	201
Fe_2O_3	254
TiO_2	7.5
CaO	3.3
HgO	8.5
BaO	2.2
Na_2O	7.1
K_2O	11
SO_3	1

At this station 80 percent of the ash is present as fly ash, while 20 percent is bottom ash.

Each of the eight pulverized coal furnaces is opposite-fired which makes them unique in Ontario Hydro installations. A water-filled bottom ash hopper is located below each boiler and collects up to 408 tonnes of ash which has a density of 1 281 kg/m^3. The bottom ash is hydraulically sluiced to a combined bottom ash/fly ash lagoon at a maximum removal rate of 90.7 tonnes per hour using jet pulsion pumps. Figure 18 illustrates the bottom ash transport system.

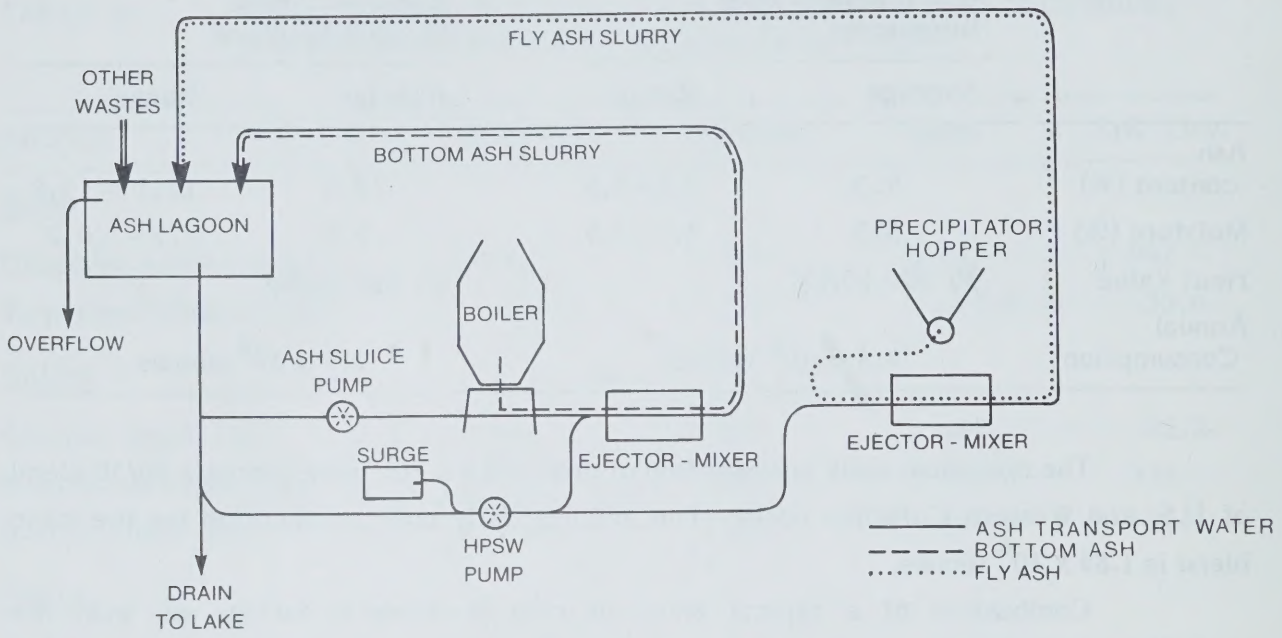


FIGURE 18 NANTICOKE GENERATING STATION ASH HANDLING SYSTEM

The lagoon, which is clay lined, has a capacity of 8.4×10^6 m^3 and covers 76.08 ha. The lagoon was designed to handle all ash for a 50 percent station load. The nominal retention time is 100 days; however, this is being reduced as the lagoon fills with ash.

Fly ash is collected using electrostatic precipitators which are 99.5 percent efficient. Ash is drawn pneumatically through air separator tanks and is discharged hydraulically to the ash lagoon. Fly ash is removed continuously in a 2.5 percent slurry.

4.3.3 Water Balance. In addition to the bottom and fly ash transport water, other waste streams entering the lagoon include flows from the sewage lagoon, air preheater washings, chemical cleaning wastes, coal pile drainage and utility plant wastes. The wastewater streams which enter the lagoon are shown in Figure 19. The water use in the generating station lagoon system is shown in Figure 20.

A constant flow of 63.1 L/s is required to transport the fly ash and vacuum cleaning refuse from the boilers to the lagoon. Bottom ash transport water entering the lagoon has four components. Water used to educt the collected bottom ash from the boilers has a flow rate of 148 L/s, while bottom ash sluicing requires 49 L/s to transport

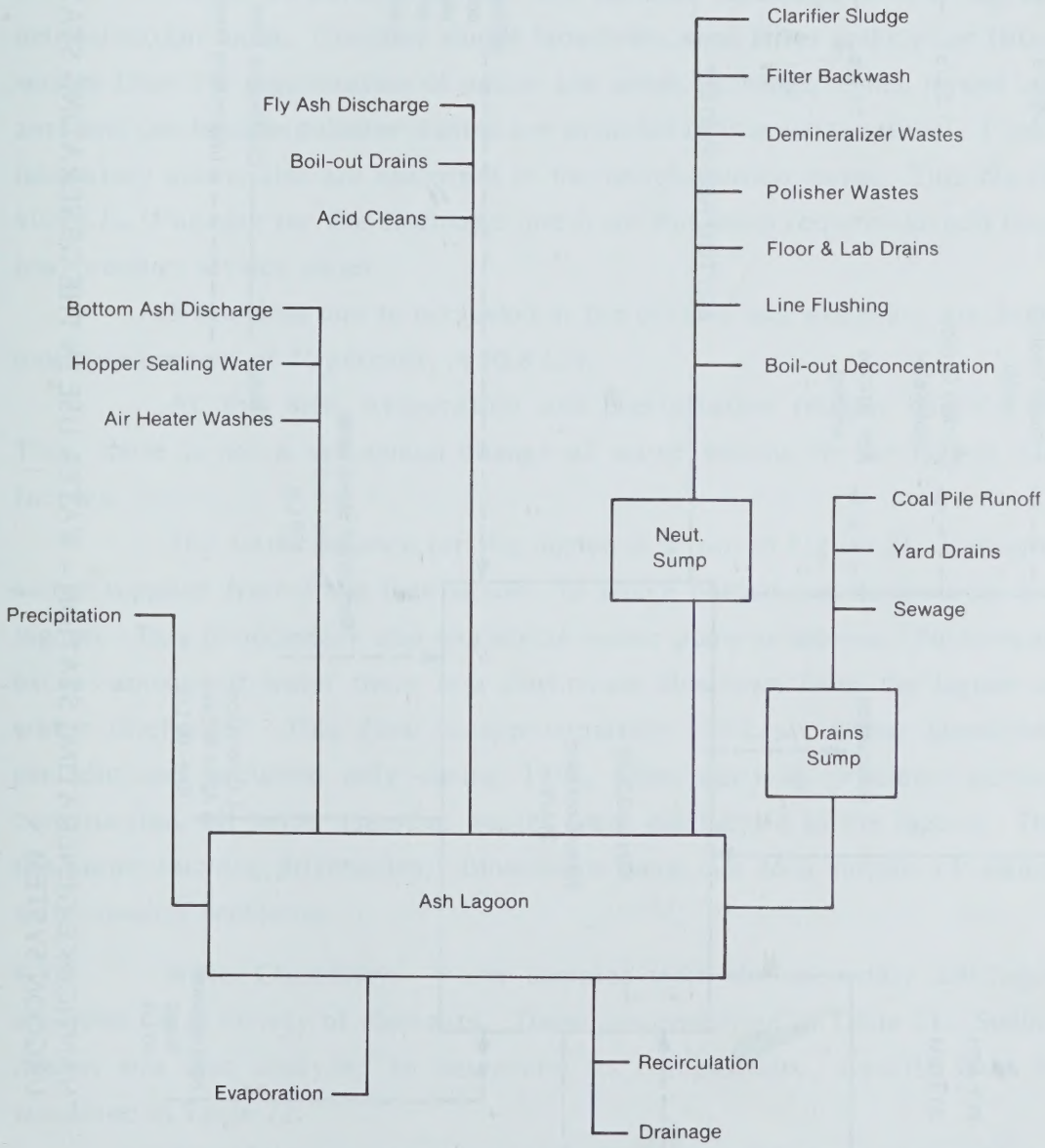


FIGURE 19 NANTICOKE GENERATING STATION - WASTE STREAMS ENTERING THE ASH LAGOON

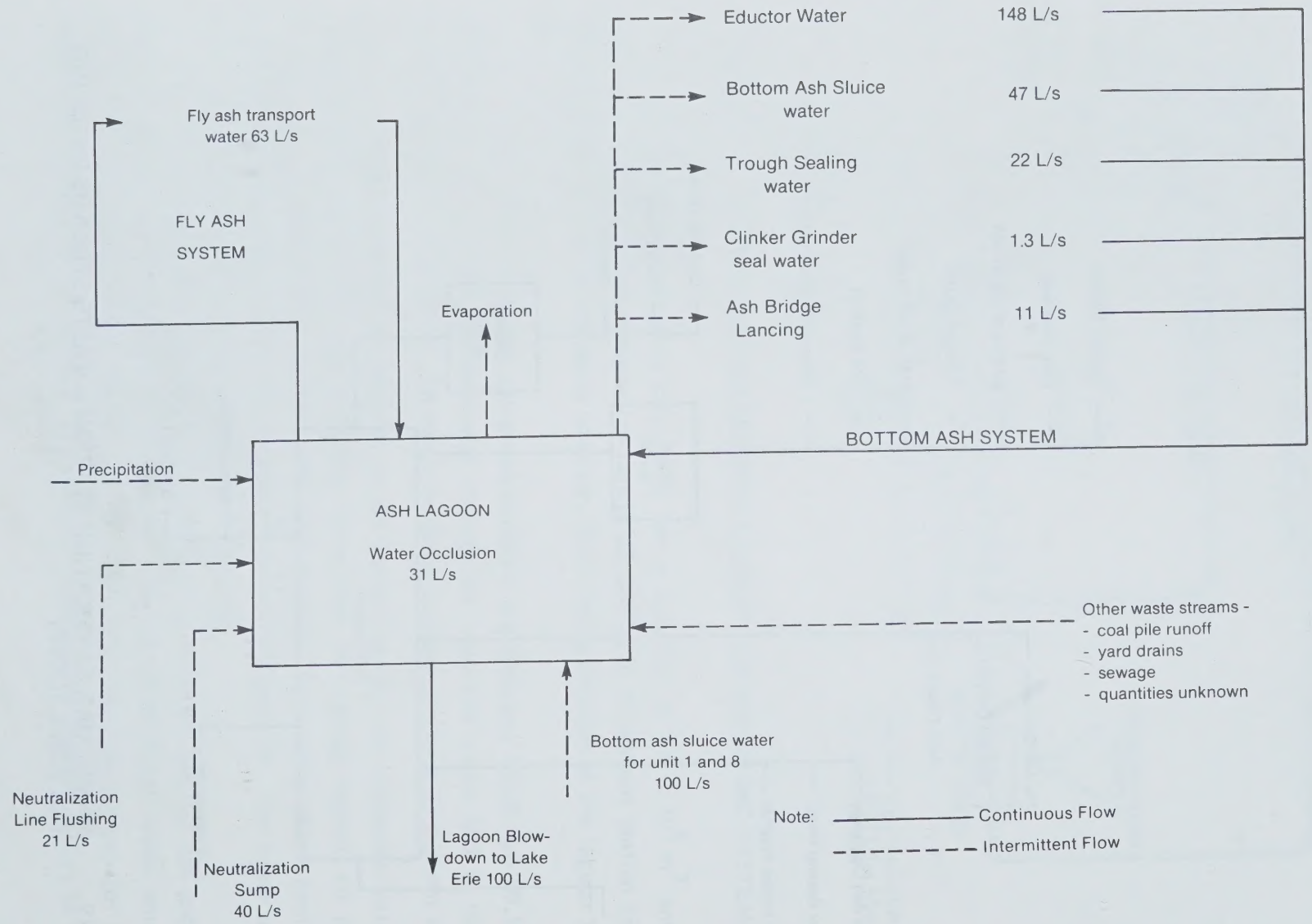


FIGURE 20 NANTICOKE GENERATING STATION - WATER USE IN THE GENERATING STATION LAGOON SYSTEM

the bottom ash from the hopper to the lagoon. Low pressure service water supplied to the bottom ash hopper consists of 22.0 L/s to maintain a seal between the ash hopper and the boiler, while 1.3 L/s are required for clinker grinder sealing water.

Under full load, ash can build up and bridge the ashpit throat. This requires water lancing at 11.4 L/s to break up the accumulation.

About 10 percent of the net aqueous discharge to the lagoon is from the neutralization sump. Clarifier sludge blowdown, sand filter and carbon filter backwashes, wastes from the regeneration of cation and anion exchange resins, mixed bed demineralizers and condensate polisher wastes are included in this waste stream. Floor cleaning and laboratory drains also are collected in the neutralization sump. This discharge is about 40.4 L/s. Flushing for the discharge line from this sump requires an additional 20.8 L/s of low-pressure service water.

Water loss due to occlusion in the bottom ash, assuming the disposed ash has a moisture content of 70 percent, is 30.8 L/s.

At this site, evaporation and precipitation roughly balance over the year. Thus, there is not a net annual change of water volume in the lagoon due to climatic factors.

The water balance for the lagoon is shown in Figure 21. Low-pressure service water supplied from Lake Erie is used to sluice bottom ash from units 1 and 8 to the lagoon. This is necessary due to recycle water pump problems. To compensate for this excess amount of water there is a continuous blowdown from the lagoon to the cooling water discharge. This flow is approximately 100 L/s. Other blowdowns have been periodic and occurred only during 1974, when start-up problems occurred. During construction, all boiler cleaning wastes were discharged to the lagoon. This resulted in the commissioning difficulties. Blowdowns were due to a surplus of water rather than water quality problems.

4.3.4 Water Chemistry. Water samples from the secondary ash lagoon have been analyzed for a variety of elements. These are presented in Table 21. Sediment from the lagoon was also analyzed to determine its composition. Results from this work are tabulated in Table 22.

The elements present in highest concentrations in the pond water included boron, calcium, potassium, sodium and strontium. Analysis of sediment samples from the ash lagoon indicated that the most common elements present included aluminum, calcium,

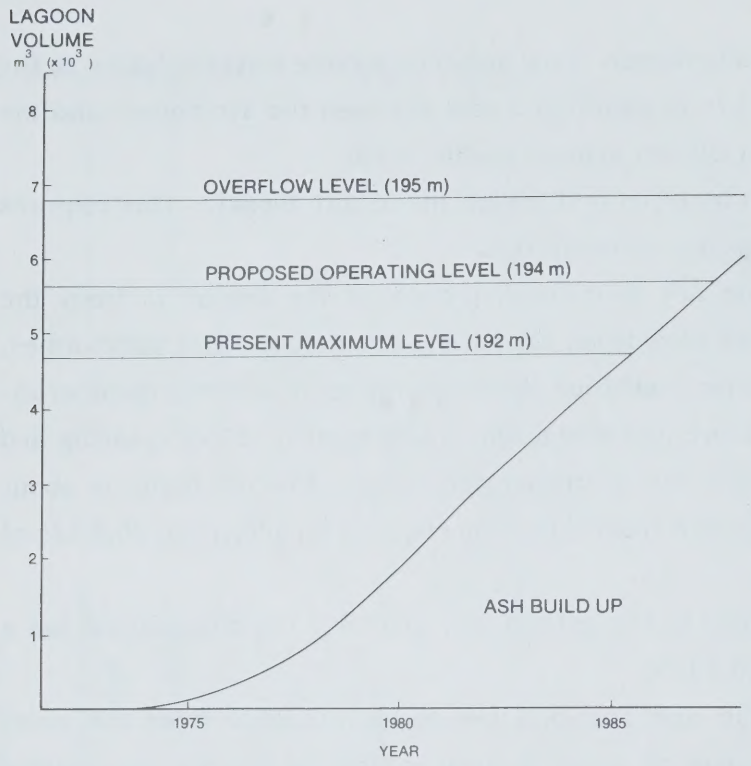


FIGURE 21 NANTICOKE GENERATING STATION ASH LAGOON VOLUMES (42)

iron, potassium, magnesium, sodium and titanium. Sediments in the primary ash lagoon contained high concentrations of aluminum, barium, clacium, iron, potassium, magnesium, sodium and titanium.

The quality of ash lagoon water during winter and summer operation and the quality of water from Lake Erie, which is the station's raw water supply, are compared in Table 23.

The lagoon water showed higher conductivity, total hardness, sulphate and total dissolved solids than the station raw water supply. There were also differences in the lagoon water between winter and summer. For example, calcium concentration was about six percent higher in the winter. Because the water temperature is lower, calcium carbonate has an increased solubility. The solubility of carbon dioxide in the lagoon water, which affects the presence of carbonate ions, would be increased by lower water temperature. However, the presence of a partial ice cover on the lagoon would reduce the transfer of CO_2 from the air into the lagoon waters.

Calculation of the Langelier Index for the lagoon water in winter gives a value of -0.3. This suggests the water is slightly corrosive. A similar calculation for water in

TABLE 21 ANALYSIS OF WATER SAMPLES FROM THE SECONDARY ASH LAGOON - NANTICOKE GENERATING STATION

Sample	Ag (mg/L)	Al (mg/L)	As (mg/L)	B (mg/L)	Ba (mg/L)	Be (µg/L)	Ca (mg/L)	Cd (µg/L)	Co (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Hg (µg/L)	K (mg/L)
Aug 10, 1978														
L1	<0.001	0.40	0.033	19.0	0.12	<0.5	39.8	<0.3	0.012	0.020	0.005	<0.004	0.05	17.1
L2	<0.001	0.38	0.032	18.0	0.12	<0.5	40.7	<0.3	0.014	0.023	0.005	<0.004	0.05	20.1
Blank	<0.001	<0.02	0.002	< 0.005	<0.001	<0.5	< 0.005	<0.3	<0.002	<0.001	<0.001	<0.004	0.04	0.2
Sept 1, 1978														
L1	<0.001	0.51	0.040	18.7	0.13	<0.5	40.5	<0.3	0.014	0.021	0.010	<0.004	0.12	19.9
L2	<0.001	0.71	0.039	17.6	0.12	<0.5	39.0	<0.3	0.016	0.022	0.016	<0.004	0.04	19.6
Blank	<0.001	<0.02	< 0.001	< 0.005	<0.001	<0.5	0.06	<0.3	<0.002	<0.001	<0.001	<0.004	0.03	< 0.03

Sample	Mn (mg/L)	Mo (mg/L)	Na (mg/L)	Ni (mg/L)	P (mg/L)	Pb (mg/L)	Se (mg/L)	Si (mg/L)	Sr (mg/L)	Th (µg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)	Zr (mg/L)
Aug 10, 1978														
L1	0.004	0.30	51.0	0.024	0.08	<0.002	0.029	1.6	3.5	0.05	0.007	0.004	0.009	0.005
L2	0.004	0.28	54.0	0.022	0.12	<0.002	0.039	1.6	3.5	0.06	0.010	0.014	0.013	0.008
Blank	<0.001	0.02	< 0.5	< 0.001	<0.07	<0.002	0.001	0.009	<0.001	0.003	< 0.001	0.001	<0.001	< 0.001
Sept 1, 1978														
L1	0.006	0.35	59.0	0.028	0.14	0.002	0.037	1.8	3.5	0.03	0.011	0.018	0.003	0.016
L2	0.003	0.31	56.0	0.026	0.18	<0.002	0.039	1.6	3.5	0.04	0.011	0.017	0.002	0.025
Blank	<0.001	<0.001	< 0.5	< 0.001	<0.07	<0.002	< 0.001	0.003	<0.001	0.003	<0.001	<0.001	0.002	< 0.001

TABLE 22 ANALYSIS OF SEDIMENT FROM NANTICOKE GENERATING STATION PRIMARY ASH LAGOON

Element	Nanticoke Sediment (mg/kg)
Al	91 400
Ag	0.4
As	84
B	39*
Ba	1 800
Be	10
Ca	18 050
Cd	10
Co	43
Cr	130
Cu	72
Dy	4.4
Eu	2.1
Fe	210 000
Ga	40
Hg	0.1
K	9 970
La	75
Mg	5 600
Mn	315
Mo	20
Na	2 640
Ni	91
P	720
Pb	15
Sc	24
Se	7
Si	166 000
Sr	920
Th	18
Ti	4 800
U	9.3
V	147
Yb	7
Zn	151
Zr	170

* Highly uncertain values

TABLE 23 NANTICOKE GENERATING STATION ASH LAGOON AND RAW WATER SUPPLY QUALITY

Analysis	Ash Lagoon March, 1979	Ash Lagoon August, 1979	Lake Erie
Temperature at Sampling time (°C)	40	22.5	
Colour (ASTM No.)	5	20	
Total Solids (mg/L)	2 540	2 330	
Suspended Solids (mg/L)	130	40	
Turbidity (NTU)	4.0	2.0	
pH	7.40	8.56	7.3
Conductivity (μmhos/cm)	2 280	2 020	315
Total hardness (mg/L $CaCO_3$)	1 420	1 400	136*
Calcium hardness (mg/L $CaCO_3$)	1 310	1 230	100*
Magnesium hardness (mg/L $CaCO_3$)	110	170	36*
Total alkalinity (mg/L $CaCO_3$)	42	71	85*
Sulphate (mg/L SO_4^{-2})	1 390	1 253	25
Chloride (mg/L Cl)	264	31.1	22
Silica (mg/L SiO_2)	3.18	2.87	
Sodium (mg/L Na^+)	61		14
Phosphorous (mg/L)	0.10	0.08	
Calcium (mg/L)	524*	492*	40
Magnesium (mg/L)	26*	41*	9
Bicarbonate (mg/L)	51*	87*	104
TDS (mg/L)	2 410*	2 290*	220

* Calculated from the other analyses.

the summer yields an Index value +1.5 which would mean that the water has a slight potential for scale. This increase in scaling potential can be explained by higher pH, calcium and magnesium during the summer.

The levels of SO_4^{-2}, Ca^{+2}, Na^+, HCO_3^- and Mg^{+2} increased as shown in Figure 22. The downward dips in these levels coincide with the drawdowns from the lagoon.

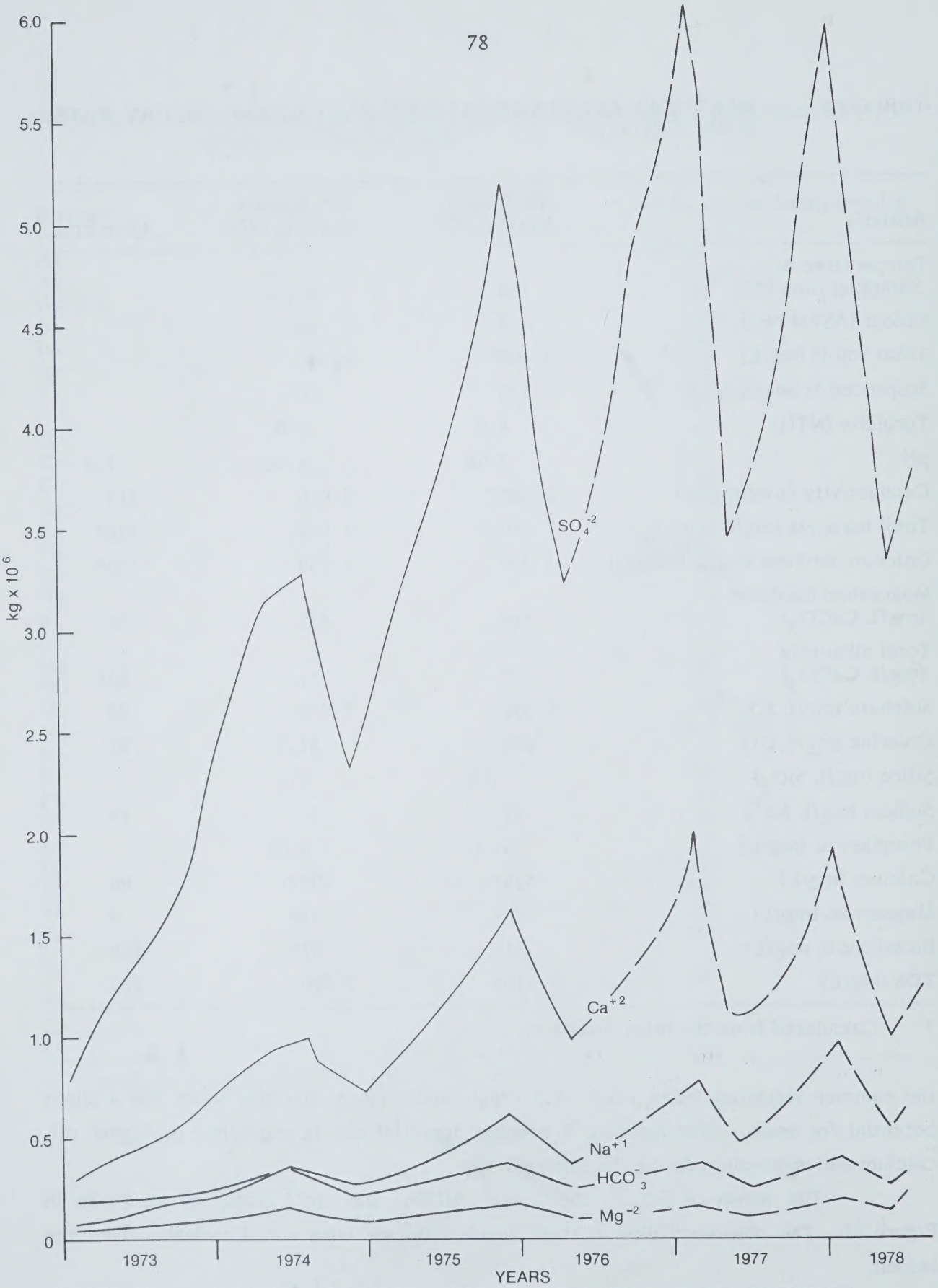


FIGURE 22 NANTICOKE GENERATING STATION ASH LAGOON CHEMICAL CONTENT (42)

In spite of the scaling index, which predicts a slight potential for scale, no scale was present in any part of the system.

4.3.5 Mechanical Problems. The major concern about the operation of the recirculation system is the steadily increasing levels of ash solids and certain chemical constituents in the lagoon. All ashes produced at the station and some other station wastes are disposed of in the one lagoon. As the ash volume increases, the retention time of the lagoon is reduced as shown in Figure 23. This may adversely affect the quality of the recycle water. This is particularly important because this lagoon is used to settle both fly and bottom ash. Should this situation continue, solids may begin to carry over into the recirculation system. It is likely that these would be fly ash particles which have much longer settling times in comparison to bottom ash particles.

The effect of diverting a portion of the fly ash is shown in Figure 23. If all the fly ash is disposed in the lagoon, by 1985 the number of lagoon turnovers will exceed 50 per year. If 90 percent of the fly ash is diverted, there will be five turnovers per year, which should maintain the ash lagoon water quality.

4.3.6 Summary. The combined ash lagoon at Nanticoke Generating Station is maintained at a fixed water level by overflowing excess water to the cooling water discharge. This is approximately 100 L/s. Over the year evaporation and precipitation roughly balance; therefore, excess water in the lagoon can come from two sources. The lagoon receives most of the plant waste streams, including coal pile runoff, demineralization wastes and sluice waters for the transport of fly ash. The more significant excess water source is the sluice water for bottom ash removal from units 1 and 8. The recirculating water pumps for the station have insufficient capacity to supply sluice water from the lagoon to all units. Units 1 and 8 use 100 L/s of low pressure service water from Lake Erie for bottom ash sluicing. To compensate for this additional water and to maintain a fixed lagoon water level, an equal amount must be discharged. This blowdown is necessary to balance the volumes of water in the system and is not done to reduce concentrations of chemical constituents in the lagoon. This water balancing constitutes a loss equivalent to 25 percent of the bottom ash sluicing water and a much smaller percentage of the total waste entering the lagoon.

The bottom ash produced at this station has good settling properties and there has been no evidence of scale formation in the recirculating system to date. Two major problems prevent the complete closing of the recirculation system. Continuous blowdown of the lagoon is required to compensate for the sluicing of bottom ash with raw water in

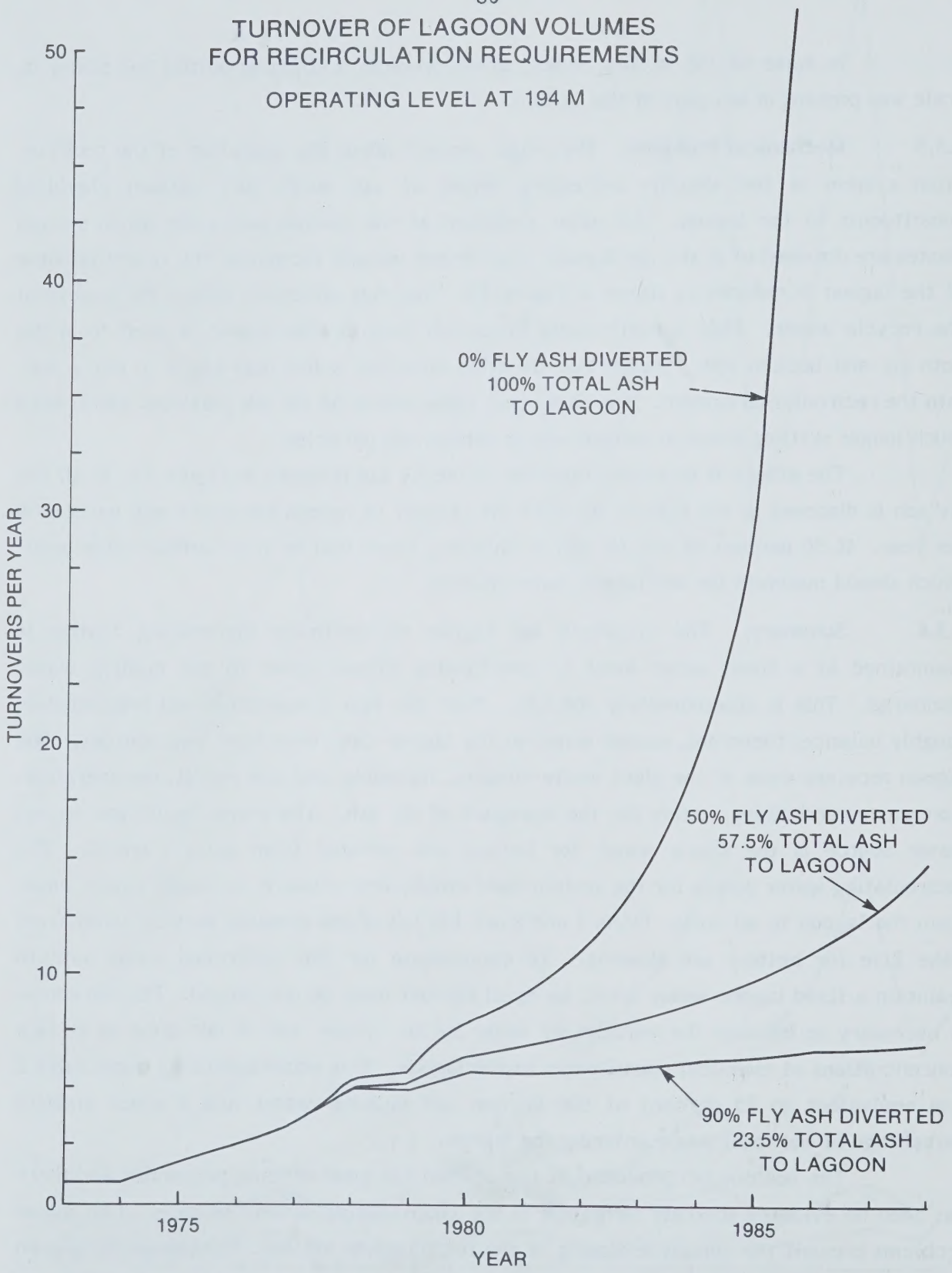


FIGURE 23 NANTICOKE GENERATING STATION - EFFECT OF ASH DISPOSAL VOLUME ON LAGOON RETENTION TIME (42)

units 1 and 8. The pump system would require modification to eliminate this excess water source. Secondly, additional capacity must be provided to prevent the eventual decline in recirculated water quality due to sources other than the bottom ash system.

4.4 Sundance Thermal Plant

4.4.1 Plant Description. The Sundance Thermal Plant is located near Kapasiwin, Alberta, approximately 80 km west of Edmonton, Alberta. Operated by Calgary Power Limited, the plant has six units in operation. Unit 1, rated at 300 MW, was commissioned in 1970. Unit 2, also rated at 300 MW, was started up in 1973. Units 3, 4, 5 and 6, each rated at 375 MW, became operational in 1976, 1977, 1978 and 1979 respectively. The total installed capacity is 2 100 MW.

4.4.2 Ash Handling System. The fuel burned at the station is sub-bituminous coal from the nearby Highvale Mine. Coal is brought to the station by coal hauler and is characterized as follows:

Parameter	Percent
Moisture content	20.4
Ash	13.6
Volatile	29.5
Fixed carbon	36.5
Sulphur	0.21
Calorific value	18 930 kJ/kg

Bottom ash resulting from the combustion of this coal typically contains the following elements:

Element	Percent
SiO_2	55
Al_2O_3	24.2
Fe_2O_3	3.8
Na_2O	2.0
K_2O	0.7
CuO	9.7
MgO	0.8
P_2O_5	0.9
S	0.03
Loss on ignition	2.7

By a separate analysis, bottom ash was shown to also contain:

Titanium dioxide	0.92 percent
Manganese dioxide	0.05 percent
Chromium oxide	0.01 percent

Under full load, the coal consumption rate is 181.44 tonnes per hour per unit. With five units operating, the daily rate is 21 772 tonnes per day with an average ash content of 15 percent. Depending on the location in the mine where the coal originates, the fly ash to bottom ash ratio ranges between 40:60 to 60:40. Annual bottom ash production is estimated to be 2.45×10^5 tonnes. Fly ash is disposed of dry in the mine.

Each boiler is fired with pulverized coal. Bottom ash collects in the ash hopper below the boiler and passes through a clinker grinder. There are three bottom ash removal systems which operate in parallel. One system dewaters bottom ash sluiced from units 1 and 2 by a venturi pump. The second system dewaters bottom ash produced in units 3 and 4 which is sluiced by a slurry pump. A third system is used to settle the bottom ash produced in units 5 and 6 which is transported using a slurry pump. In units 1 and 2 the ash slurry has a 50 percent solids content. On the other units a 25 percent solids content is used.

All ash lines are high nickel alloy cast iron pipe which is more abrasion-resistent than cast iron pipe. The lines are not heat traced or insulated but are enclosed in a heated conduit to prevent freezing.

Twin hydrobins followed by a settling ash recirculation tank are used to settle the ash from the slurry and to supply water for bottom ash sluicing. The hydrobins and settling tanks are outside, adjacent to the powerhouse.

The bottom ash slurry is pumped to one of the two 108-m^3 hydrobins. Units 1 and 2 are sluiced every four hours for 1.75 to 2.5 hours. Units 3 and 4 are sluiced every six hours for 2 to 2.75 hours. Supernatant from the hydrobins overflows to the 510-m^3 settling tank and then to the 1 400-m^3 recirculation tank. There is continuous sludge return from the settling tank to the hydrobins at 22.7 L/s. A similar facility services the recirculation tank at a slightly higher rate. Sludges are pumped to the hydrobins. Dewatered bottom ash is removed from below the hydrobins by mine haul trucks. The transport and disposal is the responsibility of the Manalta Mine Co., Highvale Mine.

Bottom ash contains 25 to 35 percent moisture content when removed from the hopper. Of this ash, 65 percent is worked into the spoils area, 25 percent is stored at an emergency dump site, and 10 percent goes to ash sales.

Mill rejects from the coal grinding are stored in a holding tank and are periodically sluiced with the bottom ash. These pyrites are disposed of with the bottom ash through the hydrobin system.

4.4.3 Water Balance. Figure 24 shows a schematic drawing of the bottom ash handling system for this station. Units 1 and 2 require 273 L/s for sluicing bottom ash, while 182 L/s are required for bottom ash sluicing in units 3 and 4. In units 5 and 6 182 L/s are used to sluice the accumulated bottom ash. Ash is removed from the hydrobins with a moisture content of 25 to 35 percent. Based on the operation of units 1, 2, 3 and 4 this occlusion is equivalent to a loss of 23.4 L/s which is 11 percent of the estimated average sluice water flow of 217 L/s.

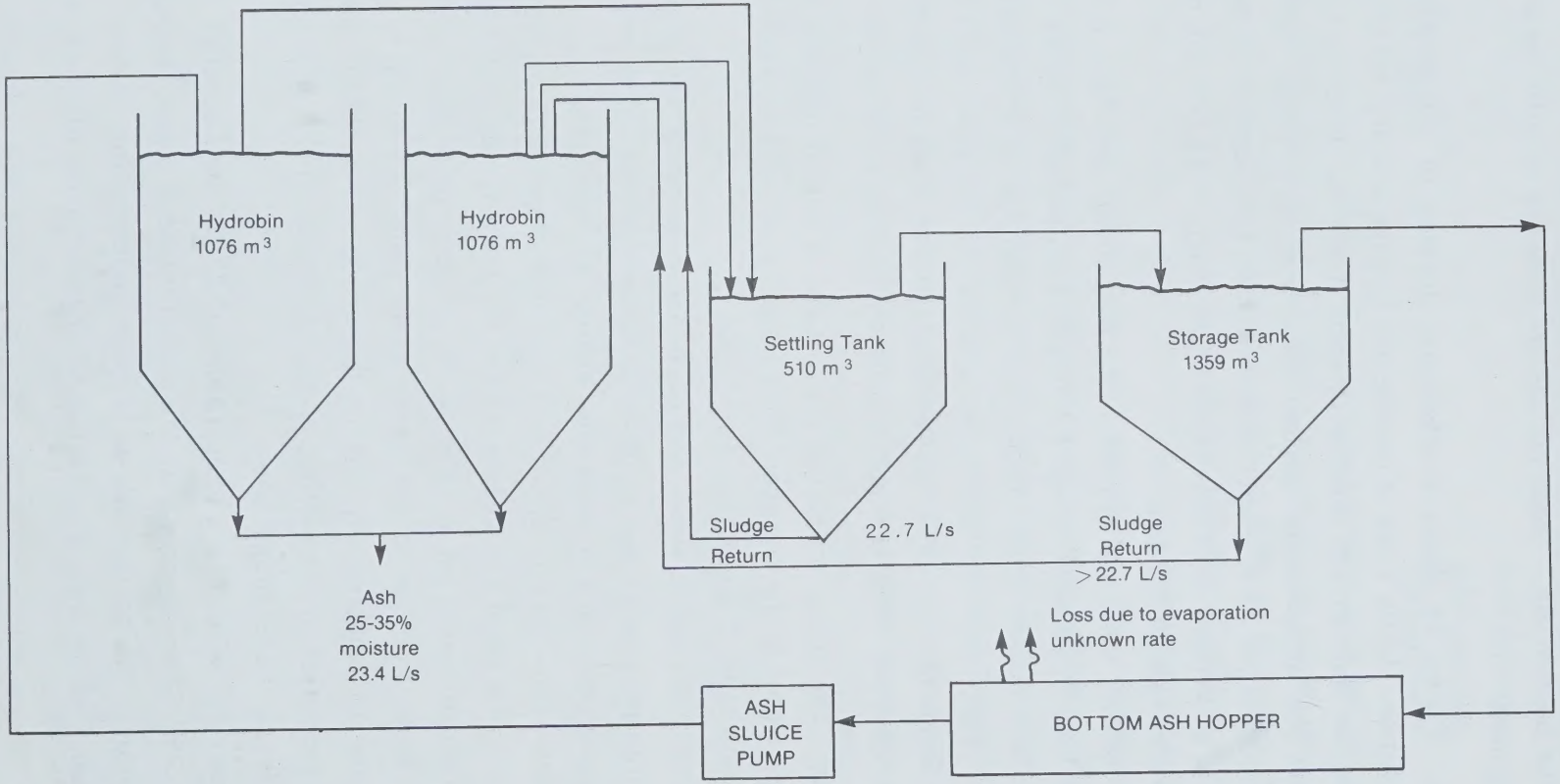
There is no blowdown from the system. The only losses are those into the boiler from the bottom ash hopper and seal trough by evaporation, occluded water in the bottom ash, and losses due to leaks and spills. Losses due to leaks and spills are assumed to be around five pervent. Water from the system is also used to wet down fly ash for transport to prevent dust problems. No other wastewater streams from the generating station enter the hydrobins. Makeup water is supplied from the cooling water canal.

4.4.4 Water Chemistry. The sluice water has shown signs of enrichment due to the continuous recycling. Sluice water in the transport lines ranges from 37.8 to 48.9°C and has a pH of around 10 for units 1 and 2, and 12 for units 3 and 4.

Analyses of bottom ash sluice water and plant make-up water are shown in Table 24. Changes in the transport water due to recirculation are evident. The pH, total dissolved solids, total suspended solids and calcium show significant increases.

On the ash sluice side, units 1, 2, 5 and 6 have not shown any evidence of scaling; however, in units 3 and 4 there is evidence of $CaCO_3$ scale buildup. The sluice water was analyzed and shown to have a pH of 12 at 48.9°C. Operating personnel believe that units 1, 2, 5 and 6 are scale-free due to the higher water velocities during sluicing. Consideration has been given to adjusting the pH in the sluice water return lines by acidification to control the formation of the calcium carbonate scale. There have been no scaling problems with the recycle water return lines.

Assuming the make-up water has a temperature of 25°C, the Langelier Index gives a scaling value of +0.79. This suggests that the station makeup water has scaling potential even before it contacts the bottom ash or is recirculated in the system. The water that is used to transport ash in units 3 and 4 has a Langelier Index of +5.14, which



Unit	Method of Ash Transport	Sluice Flow Rate and Pressure
1 and 2	Venturi	237 L/s @ 1723 kPa
3 and 4	Slurry pump	182 L/s @ 1100 kPa
5 and 6	Slurry pump	227 L/s @ 345 kPa

FIGURE 24 SUNDANCE GENERATING STATION - SCHEMATIC DRAWING OF THE BOTTOM ASH HANDLING SYSTEM

TABLE 24 BOTTOM ASH SLUICE WATER AND PLANT MAKE-UP WATER ANALYSES SUNDANCE GENERATING STATION

Bottom Ash Sluice Water Analysis

Parameter		Unit 1 and 2	Unit 3 and 4
Conductivity (μmho/cm)		688.5	1 820
pH		10.25	11.75
Temperature (°C)		37	30
Ca as $CaCO_3$ (mg/L)		116	390
Total Alkalinity as $CaCO_3$ (mg/L)		52	363
Dissolved Solids (mg/L)		116	668
Suspended Solids (mg/L)	(>5.0 μ diameter)	114	102
	(>0.45 μ diameter)	0	0
Aquapoise pH		7.85	6.5
Stability Index		5.45	1.3

Plant Make-up Water Analysis

Parameter	Plant Water Intake	Make-up to Bottom Ash System
TSS (mg/L)	4.0	128
TDS (mg/L)	376	190
P-Alkalinity (mg/L)	11	
M-Alkalinity (mg/L)	190	
pH	8.44	8.12
Ca as $CaCO_3$ (mg/L)	75	
Sulphate as SO_4 (mg/L)	1.0	
Iron (mg/L)		0.81
Oil and Grease (mg/L)		3.0
COD (mg/L)		8
Total Phosphate (mg/L)		0.035

indicates a strong tendency to scale and, in fact, this is the case in the existing system. In units 1 and 2, where no scaling has been evident, the Index value is +2.55 which suggests that a scaling problem could exist.

4.4.5 Mechanical Problems. The bottom ash sluicing system is operated automatically; however, it is maintenance intensive. Two problems have been encountered in the operation of this system.

The first affects the water use in the system and occurs when switching from one hydrobin to the next. Typically, each hydrobin is decanted on alternate days; that is, each day one hydrobin is decanted. During full load conditions in winter two decants of the hydrobins are done two or three times per week. When switching from one hydrobin to the other, the overflow from the first hydrobin and the water decanting from the second hydrobin exceed the capacity of the settling tank and cause it to overflow. This water spills directly on the ground surrounding the ash handling area. This water loss has not been estimated.

The second problem in the system is associated with the hydrobin gates used to remove the dewatered ash from the hoppers. In winter, these unheated valves freeze and do not seal properly, causing ice and ash to accumulate below the hoppers.

4.4.6 Summary. The bottom ash transport system of the Sundance Generating Station is operating without intentional blowdown. Part of the system has shown $CaCO_3$ scaling. It is estimated that approximately five percent of the water in the system is lost as spills and leaks. Water lost through occlusion with the ash is about 11 percent of the sluice water flow.

Scaling in the system may be due to two factors. The sluice water has equilibrated at a relatively high pH of between 10 to 12. The plant make-up water has an initial pH of 8.4, which favours scale formation. This water has a sufficiently high pH and calcium concentrations to form scale in cooling condensers and oil coolers in the station. Secondly, the solids content in the bottom ash sluices is approximately two to five times that used in other generating stations with similar hydrobins. This may promote higher levels of soluble species in the slurry water.

The accumulated scale in units 3 and 4 is limited to the ash sluice lines. There is no evidence of scale in the hydrobins, settling tanks or return sluice water lines. The scale, which is relatively soft and porous, was removed using a wash of 1.59×10^4 L hydrochloric acid followed by 4.54×10^3 L of 90 percent sulphuric acid. The addition of

this acid reduces the pH of the water in the recirculation system from 11.6 to 11.5. It is expected that acid cleaning will be required every other year and will be performed during routine shutdown.

4.5 Dalhousie Generating Station.

4.5.1 Plant Description. The New Brunswick Electric Power Commission operates the Dalhousie Generating Station which is located near Dalhousie, New Brunswick, about 85 km northwest of Bathurst. The station has one 110-MW capacity oil-fired unit which has been operating since 1968. A second unit rated at 212 MW will be coal-fired and was expected to be commissioned in late 1980. This station is located on Eel Bay.

4.5.2 Ash Handling System. Coal for the second unit is supplied from the Minto Coalfield in New Brunswick and is delivered by unit train. Typical analysis of coal and the composition of ash are shown below:

Coal	Parameter	Percent
	Moisture	9
	Ash	18 - 22
	Volatile	27
	Fixed carbon	40
	Sulphur	4 - 8
	Heat Value	27 910 kJ/kg
Ash	Component	Percent
	SiO_2	32.6
	Al_2O_3	12.6
	Fe_2O_3	41.7
	TiO_2	0.5
	P_2O_5	2.6
	CaO	6.0
	MgO	0.1
	SO_3	2.2
	Na_2O	0.4
	K_2O	0.4

Prior to combustion, the coal is ground to 85 percent less than 200 mesh.

Based on experience with this coal at other stations, 80 percent of the ash is fly ash and 20 percent bottom ash. The planned annual consumption is 272 100 tonnes per year. Annual bottom ash production will be about 54 420 tonnes. The pulverized coal is to be fired tangentially into the boiler.

Fly ash is collected in electrostatic precipitators and economizer hoppers and is conveyed by vacuum to a storage site where it is removed periodically by truck.

A steel plate ash hopper is mounted below the boiler furnace to collect bottom ash. This ash is transported to two hydrobins adjacent to the powerhouse. One hydrobin will receive bottom ash while the second dewaters. Supernatant water from the hydrobins flows to the primary settling tank and then to the storage tank where suspended solids are further removed from the sluice water. There are sludge return lines from both these tanks to the hydrobin.

The hydrobins are not heated nor are the ash transport lines heated, insulated or heat-traced. The slurry transport pipes are housed in a closed conduit from the station to the hydrobin building. Transport pipes will be rotated to increase their service life.

Bottom ash is to be removed by a fleet of five tractor trailers of 27.22-tonne capacity. The trucks will be loaded by discharging the bottom ash from the hydrobins into the tractors. The bottom and fly ash will be placed in an off-site disposal area located near the rail-to-truck coal transshipment area.

Also handled by the bottom ash system are the coal mill rejects. These are sluiced to a pyrite holding bin. When this hopper is filled, the pyrites are discharged through the bottom ash transport lines to the hydrobin.

4.5.3 **Water Balance.** A recirculating water system will be used for hydraulic handling of the boiler bottom ash and the pulverizing mill rejects. A schematic of the system is shown in Figure 25. Bottom ash and pyrites are sluiced to one of two hydrobins where the suspended solids settle. The supernatant overflows to a storage/surge tank and is pumped back to the system for re-use.

High-pressure jetting water is supplied to the bottom ash and pyrites hydro-ejectors and hydroveyor, and to the ash hopper for seal trough water at a rate of 189 L/s. This flow is required only when jetting water or flushing water is needed. A continuous supply of low-pressure water for the ash hopper and flushing water for the settling and storage tanks is provided at a rate of 92.7 L/s. Continuous flushing of the glands on the high-pressure and low-pressure ash water pumps and sludge return pumps for the settling and storage tanks is supplied at a rate of 1.3 L/s.

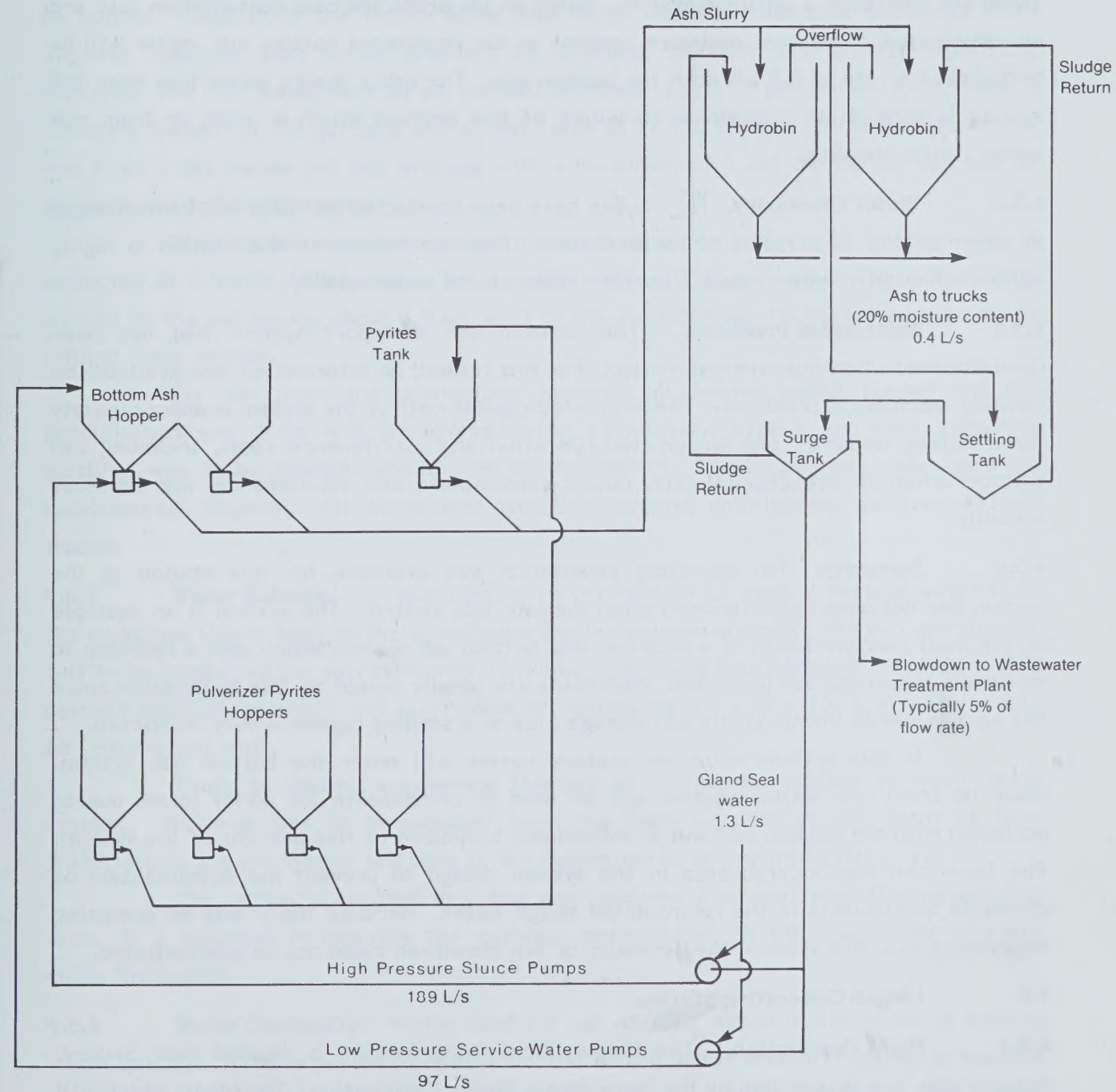


FIGURE 25 BOTTOM ASH HANDLING SYSTEM AT DALHOUSIE GENERATING STATION

In this system design, no other station wastes enter the bottom ash system. These are treated in a separate system. Based on the predicted coal consumption rate and an anticipated 20 percent moisture content in the dewatered bottom ash, water will be occluded at a rate of 0.4 L/s with the bottom ash. The other design water loss from the system is through an intentional blowdown of five percent which is made up from raw water station supplies.

4.5.4 Water Chemistry. No studies have been conducted yet to predict the changes in water quality as a result of recirculation. The coal burned at this station is highly variable in quality, which could affect the recirculated water quality.

4.5.5 Mechanical Problems. This bottom ash transport system had not been commissioned when this site was visited. For this reason, no information was available on possible mechanical problems. The estimated capital cost of the system is approximately three million dollars. The anticipated operation and maintenance costs, including ash transportation to the disposal site, power consumption and maintenance, are $460 000 annually.

4.5.6 Summary. No operating experience was available for this station as the system had not been commissioned when the site was visited. The system is an example of the most current design of a recirculating bottom ash system which uses a hydrobin to settle the suspended ash particles. Hydrobins are ideally suited to this installation since the area available for an on site ash storage area or a settling lagoon is very restricted.

In this system, no other station wastes will enter the bottom ash system. Make-up from raw water supplies will be used to compensate for water losses due to occlusion with the bottom ash and an intentional blowdown of five percent of the system. The blowdown was incorporated in the system design to prevent the accumulation of chemical constituents in the recirculated sluice water. Because there was no operating experience with this system, the necessity of this blowdown could not be substantiated.

4.6 Lingan Generating Station

4.6.1 Plant Description. The Lingan Generating Station is located near Sydney, Nova Scotia, and is operated by the Nova Scotia Power Corporation. The plant, which will have two 150-MW units, was not yet operating, but was scheduled for start-up of unit 1 in 1979 and unit 2 in 1980.

4.6.2 Ash Handling System. Bituminous coal from two sources in Nova Scotia was to be burned. Coal from the Prince Mine was to be washed while coal middlings from Victoria Junction were to be prepared by crushing, flotation and gravity separating methods. The coal would have an ash content between 10 and 13 percent on a dry basis, a moisture content of 7.5 percent, and a heat value of 27 910 kJ/kg. The consumption rate was to be 1 088 tonnes per day average with a maximum of 1 185 tonnes per day and an annual rate of 344 660 tonnes.

The boilers are fired tangentially using pulverized coal. Bottom ash is collected in a water-filled hopper below each boiler. This ash would be hydraulically sluiced to the ash lagoon about 1.5 km west of the powerhouse. Its capacity is about one million cubic metres.

Fly ash from the economizer hoppers, air heater outlet hopper and the precipitators was to be first transported using a pneumatic system and then, following wetting, was to be hydraulically sluiced to the lagoon. The lagoon was to be used for combined ash disposal. All sluice lines are above ground, uninsulated, and are not heat traced.

4.6.3 Water Balance. A recirculating system was to be used to recycle water from the combined lagoon back to the powerhouse for bottom ash sluicing. Bottom ash sluicing was to be conducted for approximately 70 minutes per eight hours of plant operation. The percent solids in the slurry will vary; however, approximately 1.24×10^6 L of water would be required per shift.

There is limited experience relating to the water balance of the recycle system. Make-up was to be supplied from the water system of the town of New Waterford to the ash system and then to the lagoon, on an as required basis.

The lagoon is located in a bog and receives drainage from the surrounding area. It is expected to overflow the spillway continuously. No other waste streams will enter the lagoon.

4.6.4 Water Chemistry. Water used for ash sluicing was initially to be of surface water quality. After a period of operation, the return water was anticipated to become alkaline due to increased concentrations of calcium, sodium, potassium, sulphates, bicarbonates and carbonates. The pH would likely exceed 7.5. Leaching tests predicted a conductance of 2 450 µmhos/cm at 10 percent solids in a sample and 4 700 µmhos/cm at 20 percent solids.

4.6.5 Mechanical Problems. Because this bottom ash transport system was not operating there is no experience with mechanical problems at this station.

4.6.6 Summary. As this system was not yet operating, no information on water quality changes, seasonal or technical problems was available. The combined bottom and fly ash lagoon would likely blowdown continuously during operation because of an accumulation of surplus water from surface drainage in the area. The quantity of blowdown would probably reflect the seasonal changes in precipitation in the area of the station.

The quality of the discharge from the lagoon would likely be adversely affected by an accumulation of both fly and bottom ash. The accumulation will reduce the ash pond volume and therefore the detention times. The quality of the recirculated transport water may be adversely affected, and eventually the operation of the recirculating system.

4.7 Boundary Dam Generating Station

4.7.1 Plant Description. The Boundary Dam Power Station is operated by the Saskatchewan Power Corporation near Estevan, Saskatchewan. The station is located on a man-made reservoir formed by a dam on Long Creek. There are presently six units operating. Units 1 and 2, rated at 66 MW, were commissioned in 1960; units 3 and 4 were started up in 1970. In 1973 unit 5, with a capacity of 150 MW became operational, while the 300 MW unit 6 began producing electricity in 1978.

4.7.2 Ash Handling System. Coal supplied to the plant is produced in a nearby strip mining operation, and is transported to the storage area in 91-tonne trucks. Typical analysis of coal is:

Parameter	Presence (Percent)
Heat value	14 650 - 15 120 kJ/kg
S	0.5
Ash	8 - 10
Ca (as oxide)	6 - 10
Mg	1 - 3
Na	4 - 6

Analysis of bottom ash from a typical coal sample is as follows:

Element	Presence (weight %)
Aluminum as Al_2O3	19.6
Calcium as CaO	11.81
Iron as Fe_2O_3	5.36
Magnesium as MgO	2.85
Phosphorus as P_2O_5	0.22
Potassium as K_2O	0.60
Silicon as SiO_2	38.71
Sodium as Na_2O	3.27
Titanium as TiO_2	1.17
Sulphur as SO_3	0.41

During peak load periods, an average of 13 242 tonnes of lignite coal are burned daily. The range of daily consumption is 8 163 to 14 512 tonnes per day, with an annual consumption of 4.17×10^6 tonnes. Approximately 50 percent of the ash collected is bottom ash.

Fly ash is collected from unit 6 by electrostatic precipitation while on units 2 through 5, 50 percent efficient mechanical precipitators are used. There is no fly ash control equipment for unit 1. The collected fly ash is transported using a vacuum system. Ash not stored in silos for future sale is transported hydraulically to the once-through combined ash disposal lagoons.

The pyrites from the coal mills are sluiced to one pyrite storage hopper per unit. The collected mill rejects are sluiced to the bottom ash hopper for transport. The bottom and fly ashes are sluiced together to the ash ponds.

Discussions of the bottom ash system are based on the design for unit 3. The same design is used for units 4 and 5. The ash removal system is similar to the one used on unit 6 and also to the combined one for units 1 and 2.

Bottom ash is collected in a water-filled ash hopper below the boiler and is hydraulically sluiced in lines separate from the fly ash in a five percent slurry to combined ash disposal ponds located west of the powerhouse. On units 3, 4, 5 sluicing is done for six hours every eight-hour shift. Lagoons are built of surface material and are unlined. The once-through lagoons discharge the sluice water back to the reservoir.

The site plan of the station is shown in Figure 26. The ash transport system is operated essentially in a once-through mode. There is an indirect recycle of some of the ash sluice water through the cooling water reservoir; however, this occurs at a very low rate.

4.7.3 Water Balance. All major water uses in the plant are supplied from a pumphouse which is located adjacent to the man-made reservoir. Water discharges from the condensers and ash lagoons are made via an open-ditch cooling water discharge. The waters eventually return to the reservoir. High-pressure bottom ash sluice pumps supply water from the cooling water inlet. Low-pressure pumps supply water from the cooling water inlet to be used to sluice pyrites from the collection hoppers to the bottom ash hoppers. This water is also used around the bottom ash hoppers for window cooling and ash flushing. Bottom ash is sluiced with a rate of 159 L/s.

Overflow from the lagoons returns to the reservoir along with the cooling water at a flow rate of 12 620 L/s. The reservoir has a capacity of 6×10^7 m^3 and covers an area of 648 ha.

Water use around the bottom ash system for unit 3 is shown in Figure 27.

4.7.4 Water Chemistry. Analyses of the water at various points in the system have indicated some changes in water quality as a result of contact with the bottom ash. These are shown in Table 25.

The lake water sample was taken at the pumphouse. The station 1 sample was taken from the cooling water flow; the station 2 sample is effluent from the ponds used to dispose of bottom ash and pyrites; while the station 3 sample is effluent from the fly ash disposal lagoon. Water samples were taken in March, 1979.

Another sampling from the same locations in the system and one sample from the Souris River had been taken in August 1978. The analyses (Table 26) show the changes in water quality throughout the system. The Souris River sample analyses can be used as a basis for comparison as they represent surface water quality in the area.

Analyses of the ash transport water show that the levels of calcium, potassium and sodium are not significantly greater after contact with the ash than in the feed water for the sluicing system. Selenium, aluminium, boron, chromium, molybdenum, strontium and vanadium are present in the lagoon overflows at increased concentrations. Concentrations of zinc are lower in the ash effluent than the lake water.

FIGURE 26 SITE PLAN OF BOUNDARY DAM GENERATING STATION

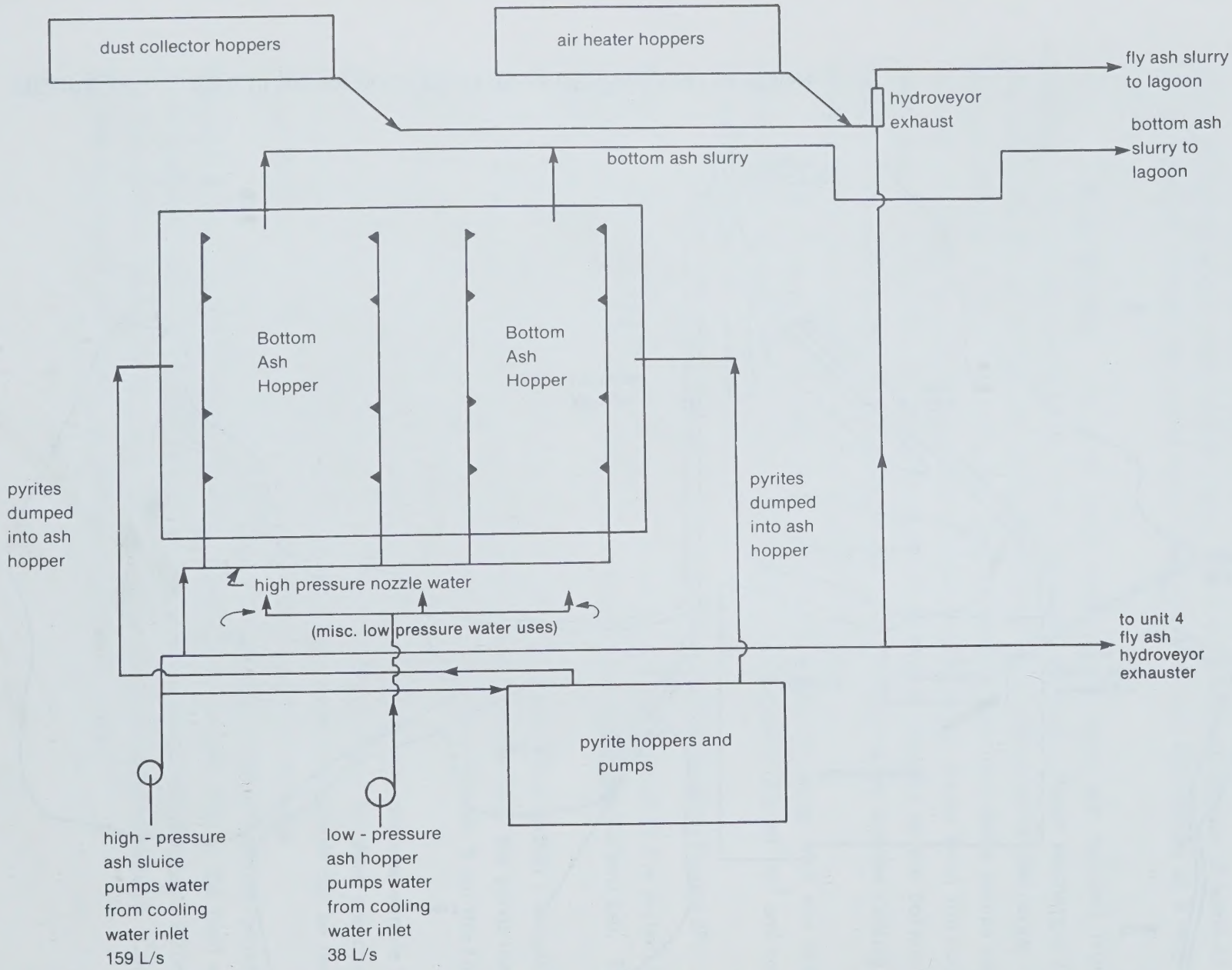


FIGURE 27 BOUNDARY DAM GENERATING STATION - UNIT 3 BOTTOM ASH HANDLING SYSTEM

TABLE 25 ANALYSIS OF WATER SAMPLES FROM THE RECIRCULATION SYSTEM - BOUNDARY DAM GENERATING STATION

Element	Concentration (mg/L)			
	Lake Water	Station 1	Station 2	Station 3
Mercury	< 0.02	< 0.02	< 0.02	< 0.02
Arsenic	< 0.005	< 0.005	< 0.005	< 0.005
Selenium	0.008	0.008	0.009	0.015
Silver	< 0.02	< 0.02	< 0.02	< 0.02
Aluminum	0.4	1.1	1.2	1.0
Boron	0.666	1.31	2.82	3.07
Barium	0.344	0.642	0.411	0.568
Beryllium	< 0.005	< 0.005	< 0.005	< 0.005
Calcium	44.6	52.2	42.7	55.2
Cadmium	< 0.01	< 0.01	< 0.01	< 0.01
Cobalt	< 0.01	< 0.01	< 0.01	< 0.01
Chromium	< 0.01	0.02	0.05	0.06
Copper	0.010	< 0.005	< 0.005	< 0.005
Iron	0.16	0.09	0.07	0.02
Potassium	12.2	13.1	11.6	12.6
Lithium	< 0.05	< 0.05	< 0.05	< 0.05
Magnesium	21.5	19.8	14.8	18.5
Manganese	0.032	0.018	0.007	0.005
Molybdenum	0.03	0.04	0.07	0.08
Sodium	101	93.8	105	136
Nickel	< 0.02	< 0.02	< 0.02	< 0.02
Lead	0.05	0.03	0.03	0.03
Silicon	1.42	2.71	2.40	2.07
Strontium	0.75	1.27	1.47	1.95
Tellurium	< 0.05	< 0.05	< 0.05	< 0.05
Titanium	< 0.005	0.010	< 0.005	< 0.005
Vanadium	< 0.01	0.03	0.04	0.04
Zinc	0.10	0.08	0.04	0.04

The ash lagoon overflows show significant changes as a result of the sluicing of ash when compared to Souris River water. There are large increases in total suspended solids, sulphate, conductivity and total dissolved solids. The pH is also increased by 1.2 units.

The Souris River water has a Langelier Scaling Index of +0.7. This suggests that it has a slight potential to scale. The lagoon overflow of station 3 has an index of +1.95 which indicates that it has a strong potential to scale. This value is lower than expected since there is a relatively large proportion of hardness due to magnesium as shown on Table 25. The feed water used for ash sluice water has an index of +2.05 which is slightly greater than the ash lagoon effluent. The reduction can be accounted for by the reduction in pH from 9.6 to 9.35 as shown in Table 26. This may be due to the presence of the more acidic fly ash sluice waters which tend to reduce the effluent pH and hence the scaling potential.

4.7.5 Mechanical Problems. No problems have been encountered with scaling of the bottom ash transport equipment. The abrasive nature of the ash appears to remove any deposits on the ash sluice side. To extend the service life of the transport pipe, lines are rotated. Main problem areas are at the elbows in the lines. Consideration has been given to rubber-lined pipe or cast iron pipe to lessen the problem. No difficulty has been evident with winter operation of the system. The system is almost continuously in service; therefore, water in the ash sluice lines does not have the opportunity to freeze.

4.7.6 Summary. The ash transport system at this station cannot be considered to be operating in a closed-cycle mode. The ash pond effluents drain into the reservoir and the reservoir water is used for all cooling and service in the station. The ash pond overflow is only a small portion of the total water volume in the system and is greatly diluted in the cooling water return ditch and in the reservoir. The sluiceway, located at the north end of the reservoir, can be used to reduce the stored water volume. Surplus water can be discharged to maintain a specified water level.

This station is a case where a completely closed bottom ash transport system may require some form of sidestream treatment to control scaling. The ash pond overflow water has a high potential to scale even when used on a once-through basis. Recirculating this water without dilution in the reservoir could cause a scaling problem. Operation of the bottom ash transport system in the current mode does not cause the formation of scale.

TABLE 26 WATER QUALITY AT VARIOUS LOCATIONS IN THE RECIRCULATION SYSTEM - BOUNDARY DAM GENERATING STATION

Sample	pH	Hardness as $CaCO_3$ (mg/L)	M-Alk. as $CaCO_3$ (mg/L)	Na (mg/L)	TDS (mg/L)	TSS (mg/L)	PO_4 (mg/L)	Chloride (mg/L)	Sulphate (mg/L)	Cond. ($\mu S/m^2$)	Diss. O_2 (mg/L)	BOD (mg/L)	COD (mg/L)	Free NH_3 (mg/L)	Temperature (°C)
Souris River at No. 18 Highway (background water)	8.15	160	190	72	610	9	1.0	8	104	750	8.6	3.7	148	0.13	22
Cooling water to outlet Canal	8.55	210	200	80	630	160	<1.0	9	125	780	7.4	5.0	55	0.34	29.5
Ash Lagoon Overflows															
Station 1	9.6	188	142	90	600	240	<1.0	8	150	740	9.1	1.8	45	0.15	20
Station 2	9.55	158	134	100	690	250	<1.0	9	180	840	9.8	1.0	42	0.25	18
Station 3	9.35	236	192	110	950	330	<1.0	9	270	1 140	9.4	1.6	39	0.28	18

4.8 Bruce Mansfield Generating Station

4.8.1 Plant Description. The Bruce Mansfield Generating Station is owned and operated by the Pennsylvania Power Company at Shippingport, Pennsylvania. The plant is located on the Ohio River approximately 65 km west of Pittsburgh. Two 850-MW units were on stream with a third unit under construction.

4.8.2 Ash Handling System. The station is fueled on bituminous coal supplied from two sources. The primary source is a captive mine in southeast Ohio. This coal is processed in a wash plant. The secondary source is a strip mine operation near Pittsburgh.

Typical ultimate analysis of the coal blend is:

Parameter	Percent
Ash content	15.45
Moisture content	7.56
Sulphur	3.10
Heat value (kJ/kg)	26 370

The total coal burned per year is 2 484 273 tonnes or 6 793 tonnes per day.

Analysis of bottom ash by x-ray techniques has indicated the following components; however, no quantitative data was available to provide a more detailed information on the ash composition:

Element	Presence
Fe_3O_4	Major
Fe_2O_3	Minor
SiO_2 (Alpha quartz)	Minor
$3Al_2O_3 \cdot 2SiO_2$ (Mullite)	Minor
$CaCO_3$	Trace
Sulphur-rich spheres	Trace

After combustion, 85 percent of ash is present as fly ash and 15 percent is present as bottom ash.

The plant uses drum coal mills for coal preparation. This type of mill produces no rejects. For this reason, there is no pyrite sluice system.

Bottom ash is collected in a water-filled hopper below the boiler and is hydraulically sluiced to one of four hydrobins adjacent to the main plant building.

Dewatered bottom ash is removed from the hydrobins by open gravel trucks. Typically a 10 to 20 percent moisture content can be achieved. Each hydrobin, which has a capacity of 635 tonnes, is filled every two days. The bottom ash is removed in 35 loads in 18-tonne trucks.

The wastewater system for the plant is shown in Figure 28. The transport system was originally designed to operate automatically but now functions manually. All ash lines are made of high nickel alloy to reduce erosion by the ash-water mixture. The ash transport lines are designed to be self-draining after use. The lines and hydrobins are not insulated or heat-traced.

Sumps and pumps for the system are located in a heated building. The ash water mixture is collected for a 12-hour period and is dewatered in the hydrobin for 12 hours. As there are two ash lines per unit, up to a one day shutdown of the ash system can be tolerated.

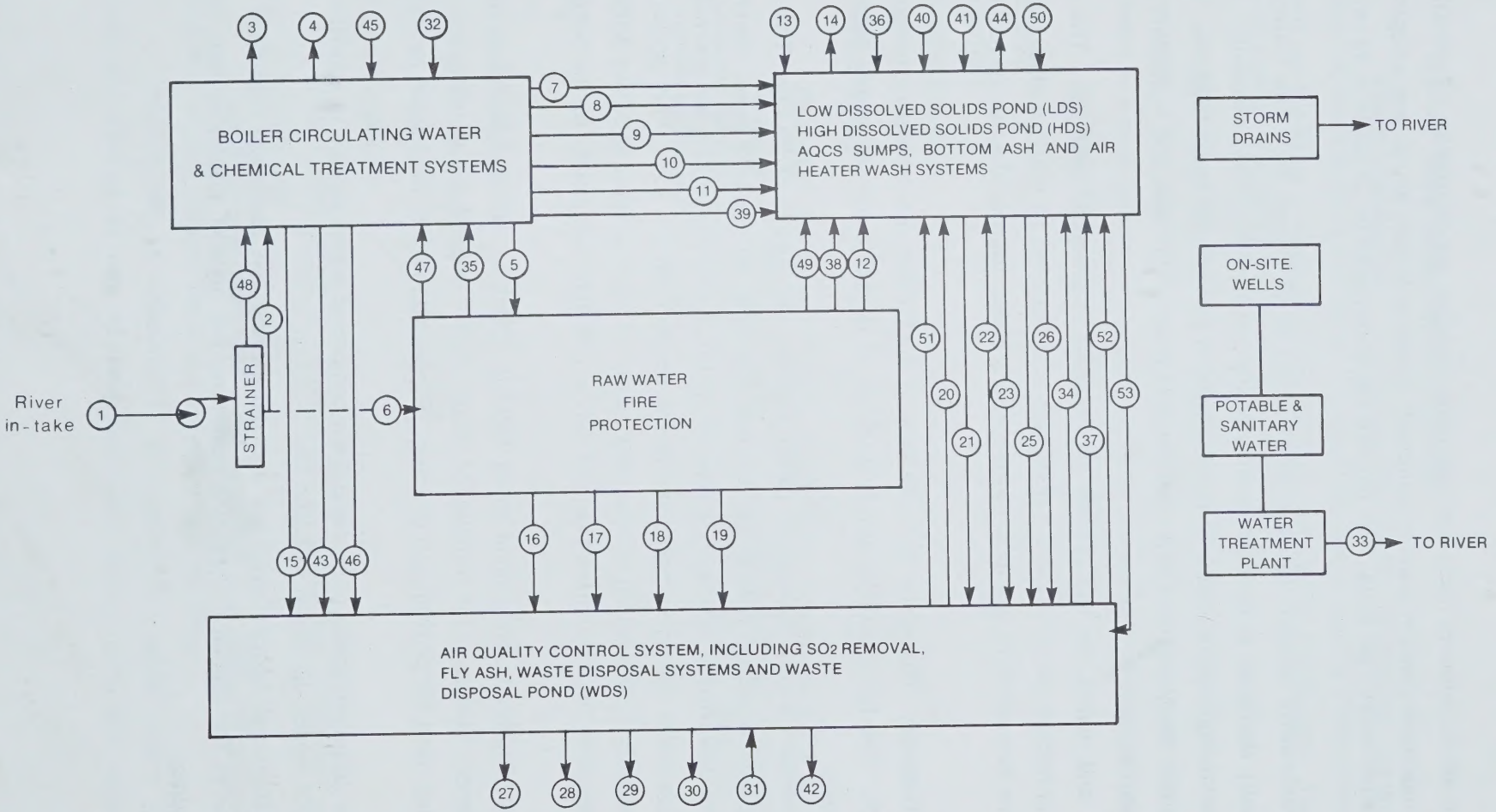
4.8.3 Water Balance. The water balance around the bottom ash transport system is shown in Figure 29. The low dissolved solids (LDS) pond is the source of water used to sluice the bottom ash.

High-pressure water is supplied to the bottom ash hopper at 95 L/s. The ash hopper and cooling weir overflow rate is 160 L/s which returns to the LDS pond. Bottom ash is sluiced to the dewatering bins with a flow of 95 L/s. The dewatering bin discharge to the pond is 94 L/s while water encapsulated in the bottom ash is 1 L/s. This occlusion rate is low because only 2.25 percent of the coal consumed at the plant becomes bottom ash. Water occluded with the ash is less than 0.5 percent of the water flow to the bottom ash hopper.

The low dissolved solids pond loses 169 L/s which is either filtered or used unfiltered as thickener makeup. This removal of water from the pond is approximately 66 percent of the water used for bottom ash sluicing. Evaporation from the lagoon averages 1.1 L/s.

The low dissolved solids pond receives a number of waste stream in addition to the bottom ash sluice water, as shown in Table 28.

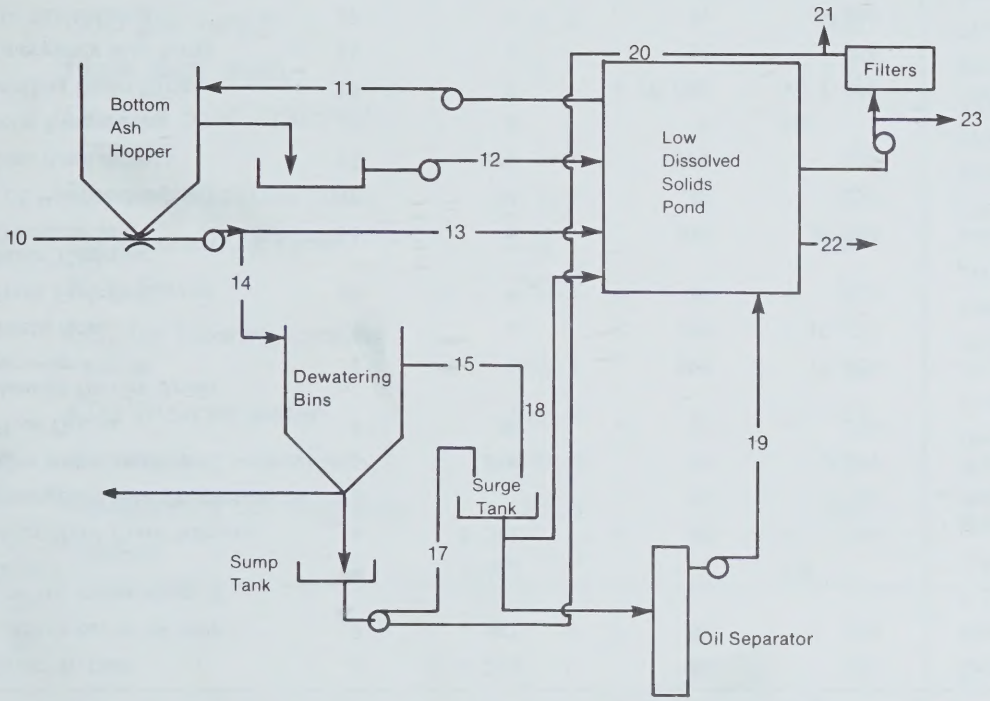
The bottom ash hopper overflow and dewatering bin discharge represent 52 percent of the flow to the lagoon. They also represent the highest suspended and total dissolved solids loading.



NOTES:

1) STREAMS ARE IDENTIFIED AND DESCRIBED IN TABLE 27.
2) ALL PROCESS AVERAGE FLOWS ARE FOR 100s OPERATION OF ALL UNITS.
3) AMBIENT CONDITIONS ARE 11°C WITH A DEW POINT OF 3.8°C.
4) FLOWS ARE FOR THREE UNITS UNLESS OTHERWISE NOTED.
5) MAXIMUM STORMS ARE FOR 30 MIN. DURATION OF 50-YEAR STORM.

FIGURE 28 WASTEWATER SYSTEM AT BRUCE MANSFIELD GENERATING STATION



Description	Line Number	Average Flow (L/s)
Bottom ash handling	10	95
Bottom ash high pressure water	11	107
Ash hopper overflow	12	160
Dewatering bin bypass	13	0
Bottom ash slurry to bins	14	95
Dewatering bin overflow	15	82
Bottom ash encapsulation	16	0.94
Sump tank discharge	17	112
Dewatering bin discharge to pond	18	94
Oil separator discharge	19	34
Filters water to bottom ash	20	0.12
Loss of pond filtered water	21	101
LDS pond evaporation	22	1.1
LDS unfiltered water to air quality control service	23	20

FIGURE 29 BOTTOM ASH SYSTEM WATER BALANCE - BRUCE MANSFIELD GENERATING STATION

TABLE 27 WASTEWATER FLOWS AND QUALITY - BRUCE MANSFIELD GENERATING STATION

Water Stream	Stream Number	Average Flow rate (L/s)	Suspended Solids (mg/L)	Total Dissolved Solids (mg/L)
River in-take	1	3 215	30	250
Cooling tower makeup	2	2 947	30	250
Cooling tower evap. & Drift	3	1 382	0	Nil
Main Plant River Returns	4	1 571	< 30	< 1 000
Emergency Fire Protection	5		30	250
Raw Water Makeup	6	244	30	250
Floor Drains	7	34	< 30	< 250
Makeup Demin. Resin back-up	8	2	100	10 000
Waste Acid	9	1	< 100	< 10 000
Flash Tank Drain	10	0	< 30	< 125
Boiler Cleaning Chemical Sol.	11	0	500	30 000
LDS Pond Makeup	12	57	30	250
Coal Area Runoff	13	59	500	150
Pond Evaporation	14	2	0	Nil
Settling Basin Sludge	15	9	< 10 000	< 1 000
Emergency SO_2 Spray	16	0	30	250
Fly Ash Makeup	17	0	30	250
AQCS Raw Water Makeup	18	144	30	250
Waste Disposal Additive Water	19	11	30	250
WDS By-pass	20	0	250 000	< 10 000
LDS Pond Filtered Water	21	103	< 30	< 2 000
ID Fan Bear Cooling Water	22	68	< 30	< 2 000
Makeup from HDS Pond	23	153	< 100	< 10 000
WDS By-pass Return	25	0	150 000	< 10 000
LDS Unfiltered Water	26	20	< 100	< 2 000
Stack Losses	27	424	0	Nil
Excess at Dam to River	28	0	< 30	< 4 000
Slaking Vapour Losses	29	8	-	-
T.D. Area Water Incapsul.	30	1 961	< 30	< 4 000
T.D. Area Run off	31	148	500	500
Main Plant Trans. Roof drainage	32	Nil	50	50
Water Treatment Plant Discharge	33	1	10	250
Flush Water Return	34	21	500	< 2 000
Raw Water for Boiler-OLN	35	0	30	250
Pond Rainfall Capture	36	1	0	Nil
pH Control Lime Survey	37	4	86 000	2 5000
Raw Water to Air Htr fire PPO	38	0	30	250
Boiler Clean Rinse	39	0	100	3 000
Transformer Sumps	40	Nil	30	250
AQCS Areas Runoff	41	1	500	1 500
WD Pond Evaporation	42	153	0	Nil
Steam for AQCS	43	4	0	Nil
Bottom Ash Encapsulation	44	1	-	-
Water in coal	45	173	-	-
Flue Gas Born Water	46	173	-	-
Floc-Former Effluent	47	28	-	250
Strainer Backwash	48	27	4 000	250
Fire Pump Tests	49	Nil	30	250
Oil Storage Area Drainage	50	0.5	50	50
Waste Sludge to WDS	51	4	1 500	< 100
WDS Makeup	52	119	< 30	< 4 000
Unfilt. Water to 1 & 2 Thickeners	53	48	< 100	< 2 000

TABLE 28 WASTE STREAMS ENTERING LOW DISSOLVED SOLIDS POND - BRUCE MANSFIELD GENERATING STATION

Waste Stream	Average Flow (L/s)	Suspended Solids (mg/L)	Total Dissolved Solids (mg/L)	Percentage of flow to Lagoon
Floor drains	3.2	30	250	0.7
Transformer sump	nil	30	250	Nil
Coal pile runoff	4.4	500	1 500	0.9
Flash back drain	0	<30	< 250	0
On-site pond - rainfall capture	1.0	0	Nil	0.2
Demineralization rinse	1.1	10	250	0.2
Boiler draining rinse	0	100	3 000	0
Raw Water	52.2	30	250	10.7
I.D. for blowing cooling water	68.1	<30	< 250	14.0
LDS filtered water	101.2	<30	< 2 000	20.8
Ash Hopper overflow	160.0	500	<2 000	32.9
Dewatering bin discharge	93.8	500	<2 000	19.3
Others	1.5			0.3

It is difficult to obtain a good estimate of the amount of blowdown from the bottom ash system because of its integration with the low dissolved solids pond of the wastewater treatment system. Plant personnel estimated the blowdown to be 10 percent of the ash water flow.

4.8.4 Water Chemistry. The low dissolved solids pond receives waste streams which include site runoff, demineralizer water, floor drainage, and coal pile runoff. The low dissolved solids pond has shown a buildup of mud-like settled solids; however, the pond is periodically cleaned out to remove this material. The pH of the pond is monitored with an effort made to keep it alkaline. It is believed that damage to the pump seals by corrosion will result if the pond becomes acidic. The low dissolved solids pond is usually alkaline; however, high runoffs from the coal pile can cause it to become acidic.

Tests were conducted to see what effect the bottom ash would have on the transport water. A representative ash sample was stirred in deionized water for 48 hours with the following results.

Parameter	Test Water Concentration (mg/L)	Station Raw Water Concentration (mg/L)
pH	8.3	7.2
Total Alkalinity (as $CaCO_3$)	22	20
TDS	294	250
Total Hardness (as $CaCO_3$)	64	
SO_4	50	25
PO_4	0.05	
Al	0.1	
Fe	0.05	
Mn	0.11	

Compared to the station raw water quality, the bottom ash sluice water as simulated by this test has slightly higher pH, alkalinity, total dissolved solids and twice the sulphate concentration.

Based on the quality of the bottom ash sluice water simulation and assuming a water temperature of 27°C the Langelier Index gives a value of -0.35, which suggests that the bottom ash sluice water would be mildly corrosive and a scaling problem would not likely exist. There has been no evidence of corrosion in the bottom ash transport system.

4.8.5 Mechanical Problems. One problem with the bottom ash transport system is the pumping capacity of the ash sluice pumps. These pumps were undersized during the design of the system, and could not maintain the flow rates required to remove the bottom ash. Ash transport lines have occasionally plugged up because of accumulated ash in the pipes. To clear the line, the section of plugged line is isolated and cleaned out using high pressure water. To help reduce the frequency of re-occurrence of the problem a flow monitoring device has been added to the discharge side of the main pumps. Operators watch this monitor to make sure flows are sufficient to prevent line plugging. This problem can be particularly serious in the winter because the water can freeze and cause pipe ruptures when low velocities cause the ash to drop out in the lines.

A second problem exists with the location of the recycle lines from the hydrobins. These pass between the powerhouse and the plant main transformers. In the event of a leak, the transformers can become wet. There is also an access problem when repair work is required on these lines and there are high erosion rates in the ash sluice pumps due to mechanical abrasion. The most susceptible are the sluice pump casings and impellers.

4.8.6 Summary. This generating station uses flue gas desulphurization and cooling towers which both require large quantities of water. In addition, the two-pond system used to treat plant wastes forms a complex wastewater system in the plant. The operating personnel suggested that there is a great deal of difficulty with the overall water balance in this plant; however, the water balance problems attributable to the bottom ash system are minimal.

The low dissolved solids pond receives many plant wastes including coal pile runoff, demineralizer wastes, floor drains and transformer sump. The bottom ash hopper overflow and dewatering bin discharge represent 52 percent of the flow to the lagoon. Water is discharged from the lagoon but is used for other purposes in the station. Uses include high-pressure service water for the bottom ash hopper at 107 L/s, utility water in the main plant at 148 L/s, and after filtering, for the air quality control system at a rate of 101 L/s.

Based on test results the recirculated water showed a potential to be slightly corrosive. No scaling was evident in the ash transport system.

4.9 Other Operating Recycling Bottom Ash Systems

A number of other steam electric generating stations use recirculating systems to transport bottom ash. Although visits were not made to these locations during this study a description of their systems is included to further indicate the diversity among recycling systems.

4.9.1 Milliken Station (29). The Milliken Station has a nominal generating capacity of 270 MW and is operated by New York State Electric and Gas Company. The station is located near Ludlowville, New York and discharges to Cayuga Lake. The bottom ash handling system is shown in Figure 30.

At this plant the bottom ash is collected in a water-filled hopper below the boiler and is hydraulically removed. Fly ash is handled dry by a pressurized collection system. Once per shift the bottom ash is sluiced from the furnaces. The ash from the sluice settles in a hydrobin system where the solids are periodically removed for disposal. The transport water is further clarified and is stored for future use in a surge tank.

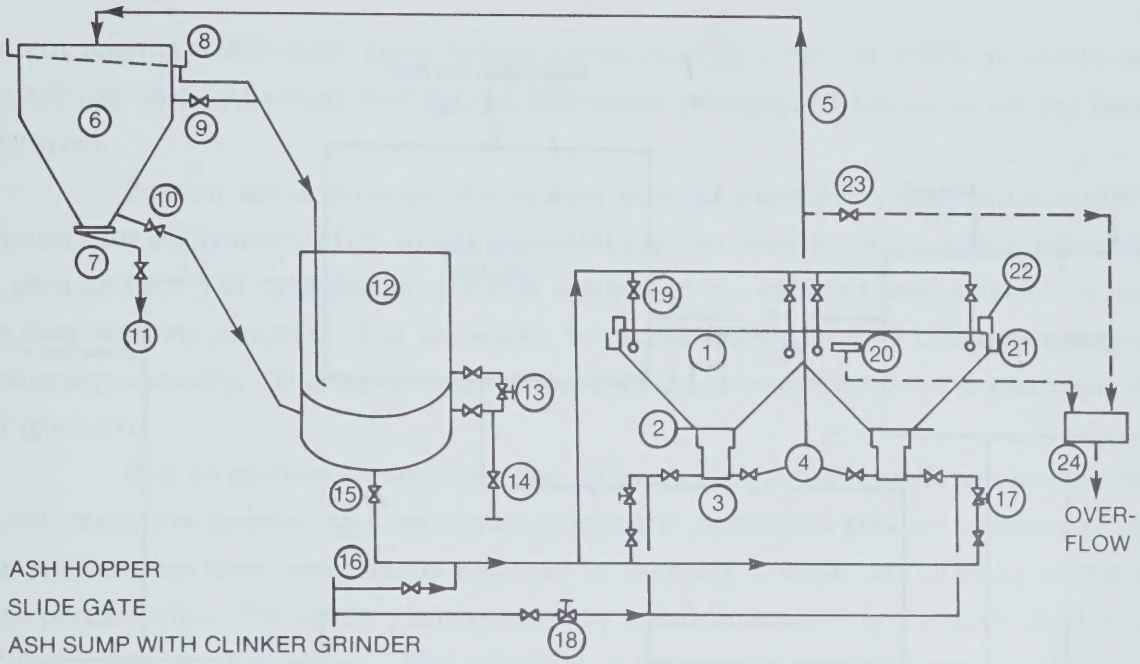
The system is designed for complete recycle. Water entrained in the bottom ash represents the blowdown from the system. The system has been operating for more than ten years successfully.

4.9.2 Centralia Steam Electric Plant (13). The Centralia Station is operated by Pacific Power and Light Company and is located near Centralia, Washington, approximately three miles from the Skookumchuck River in the Hanaford Valley. The plant has a nominal generating capacity of 1 400 MW in two equal-sized boilers. Unit 1 was commissioned in September 1971 and unit 2 in September 1972.

River water is used as makeup in the recirculating cooling system in the boilers, ash sluicing, coal washing and sanitary systems. The plant is designed to have zero discharge back to the river. The ash handling system is shown in Figure 31.

Sub-bituminous coal is supplied from a strip mine about 1.6 km from the station. The coal is characterized as having a 12 percent ash content and a heat value of 18 980 kJ/kg. The values represent averages of coal samples from the 12 beds in the adjacent coal field.

The mixed coal is transported by truck to a coal washing plant. Make-up to the washing plant is supplied from the generating plant effluent pond. Coal washing effluent is used as make-up to the ash sluicing system. The coal is crushed to at least 75



1. ASH HOPPER
2. SLIDE GATE
3. ASH SUMP WITH CLINKER GRINDER
4. ASH PUMP
5. ASH PUMP WITH DISCHARGE TO HYDROBIN
6. HYDROBIN - THIS IS WHERE ASH IS SEPARATED FROM WATER
7. UNLOADING OF ASHES INTO TRUCK
8. HYDROBIN OVERFLOW TROUGH
9. UPPER DECANT LINE
10. LOWER DECANT LINE
11. HYDROBIN DRAIN
12. SURGE TANK
13. LET DOWN LINE - THE REGULATING VALVE IS NOT IN USE. THIS IS NOW A HAND OPERATION TO LET WATER INTO LOWER COMPARTMENT OF SURGE TANK
14. HOUSE SERVICE SUPPLY LINE - NOT NORMAL MAKEUP
15. LINE FROM SURGE TANK TO ASH SUMPS
16. HOUSE SERVICE SUPPLY LINE - AT PRESENT DATE IS SOURCE OF MAKEUP - HAND OPERATION
17. REGULATING VALVE TO ASH SUMP
18. HOUSE SERVICE SUPPLY LINE - NO LONGER IN USE
19. HOPPER WASH DOWN LINE - A MEANS OF PUTTING WATER INTO ASH HOPPERS FROM MAIN CYCLE
20. ASH HOPPER OVERFLOW
21. BOILER SEAL TROUGH - WATER OVERFLOWS FROM HERE TO ASH HOPPER THUS ANOTHER SOURCE OF MAKEUP WATER
22. BOILER FEED PUMP HYDRAULIC COUPLING COOLING WATER
23. DRAIN BACK LINE - DRAINS ASH PUMP DISCHARGE LINE
24. OVERFLOW TROUGH-DISCHARGES INTO CIRCULATING WATER DISCHARGE

FIGURE 30 MILLIKEN GENERATING STATION BOTTOM ASH HANDLING SYSTEM (29)

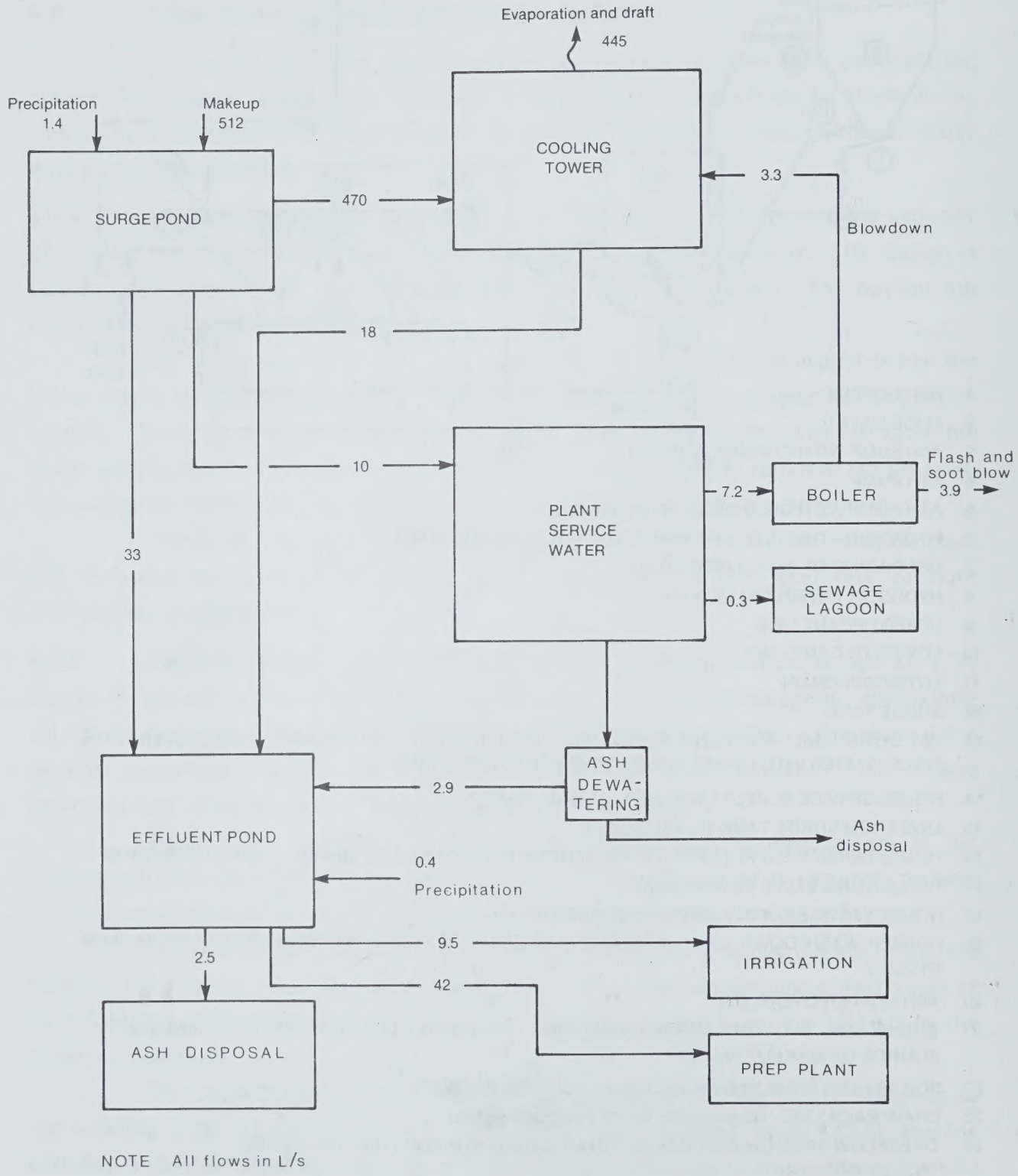


FIGURE 31 CENTRALIA GENERATING STATION BOTTOM ASH SYSTEM WATER BALANCE (13)

percent passing a 200-mesh sieve before combustion at a rate of 9 070 to 10 900 tonnes per day per unit. At a coal feed rate of 490 tonnes per hour, 49 tonnes of ash per hour are generated.

Bottom ash is hydraulically sluiced to three dewatering bins continuously. Ash dewaters for eight hours after which the solids are removed by truck to the mine site to be used as fill. The hydrobin overflow is pumped to the effluent pond where it is used in the coal washing process. The blowdown from the system is 0.43 L/min per megawatt generating capacity. The water balance and recirculation system for this plant are shown in Figure 31.

Due to problems caused by the difference in actual and design bottom ash to fly ash ratio, the dewatering lines cannot handle the continuous flow of bottom ash slurry. The problem has been temporarily resolved by dumping bottom ash directly on the plant floor periodically. The ash is then removed by small bulldozers and trucks which dispose of the solids in the mine. This requires a continuous cleanup and results in high maintenance and overhead expenses.

4.9.3 Hayden Station. The Colorado Utilities Electrical Association Inc. operates the 460-MW capacity Hayden Station. The station operates on a zero discharge principle. The plant, located near Hayden, Colorado, draws approximately 190 L/s from the Yampi River, and has no discharge (13). The station has two units. Unit 1 was commissioned in 1965 and has a generating capacity of 201 MW. Unit 2, started up in 1976, has a 282 MW capacity. The plant, burned 5.90×10^5 tonnes of bituminous coal with an average ash content of 10.66 percent in 1975. Approximately 6.26×10^4 tonnes of ash were generated.

The dry bottom ash furnace burns pulverized coal. Fly ash is removed by a dry system, while bottom ash is transported using a wet recirculating system. The ash produced at this station is returned to the mine for fill.

The main component in the water recirculation system at this station is the wastewater concentrator. As the recycled water quality deteriorates, it is eventually introduced to the waste concentrator. The operating principle of this process is described in Section 6 of this report. This unit produces water for use in boilers or other equipment which require high purity water. Wastes of low quality that cannot be recycled are pumped to an evaporator pond. These include wastewater concentrator wastes, clarifier blowdown, ash system blowdown and demineralizer regenerant wastes. The wastewater system for this station is shown in Figure 32. It should be noted that the evaporation exceeds precipitation by 42.4 cm per year.

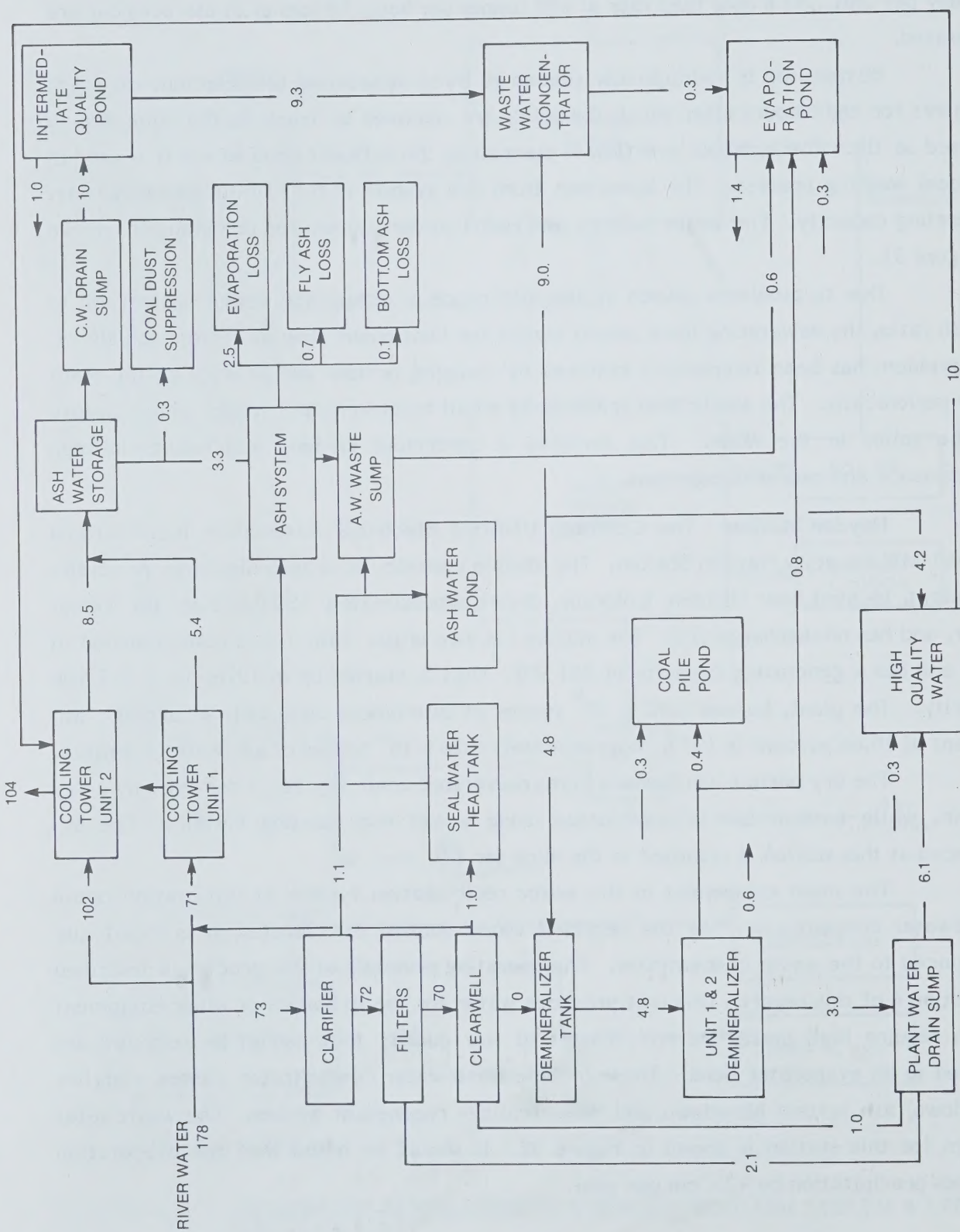


FIGURE 32 HAYDEN GENERATING STATION - WATER BALANCE FOR STATION WASTEWATER SYSTEM (13) (Annual Average Flow Rate on a Continuous Basis L/s)

Water loss from the recirculation ash sluicing system is due to evaporation and miscellaneous losses associated with ash conditioning in conjunction with transport. The average daily makeup for 460 MW capacity is 4.73 L/s or 1 365 L/t ash (13). Sluice water is stored in two ash water storage tanks and is used as required to transport ash to one of two ash settling tanks. One receives the ash slurry, while the other dewaters. Settled ash is transported to a dewatering bin while the supernatant is pumped to the wash water storage tanks. Settled ash is dewatered by means of air blown through the sludge. This is done for eight hours once per day. Dewatered bottom ash is combined with dry fly ash for transportation back to the mine.

The generating station is located in an arid area of the United States. Every effort is made in the operation of the plant to reduce the usage of water. For this reason, waste streams in the plant contain high concentrations of chemical constituents. Because of the high cost of water and its treatment, the use of a waste concentrator is justified. Since evaporation greatly exceeds precipitation, concentrated waste streams can be allowed to evaporate in drying ponds, allowing the plant to achieve zero discharge. Based on the operating experience at this plant it is evident that wastewater systems that contain high levels of chemical contaminants can be operated without scaling problems.

4.9.4 Four Corners Station. The Arizona Public Service Company operates the Four Corners Generating Station near Farmington, New Mexico. The plant has five units with a generating capacity of 2 150 MW (34). The coal utilized at this plant is composed of 20 percent ash and 0.5 - 1.0 percent sulphur with a heating value of 21 630 kJ/kg. The plant uses a cooling pond and wet bottom ash sluicing system for all units. Particulates are removed from stack gases by wet scrubbing in units 1, 2 and 3 while electrostatic precipitators are used for units 4 and 5. Approximately 80 percent of the ash generated is present as fly ash. Units 1, 2 and 3, which together deliver about 500 MW capacity, have a common bottom ash handling system. A Resource Conservation Company brine concentrator unit is part of the water recycle system for the stack gas scrubber systems.

Figure 33 shows the water flows for this station, while Table 29 presents the characteristics of the major waste streams. The bottom ash handling system is not truly recirculated because the effluents from the hydrobins are discharged first to the cooling pond before they are reused in the powerhouse for ash sluicing. The blowdown from the cooling pond is much greater than the discharge from the bottom ash hydrobin - 115 L/s compared with 69 L/s.

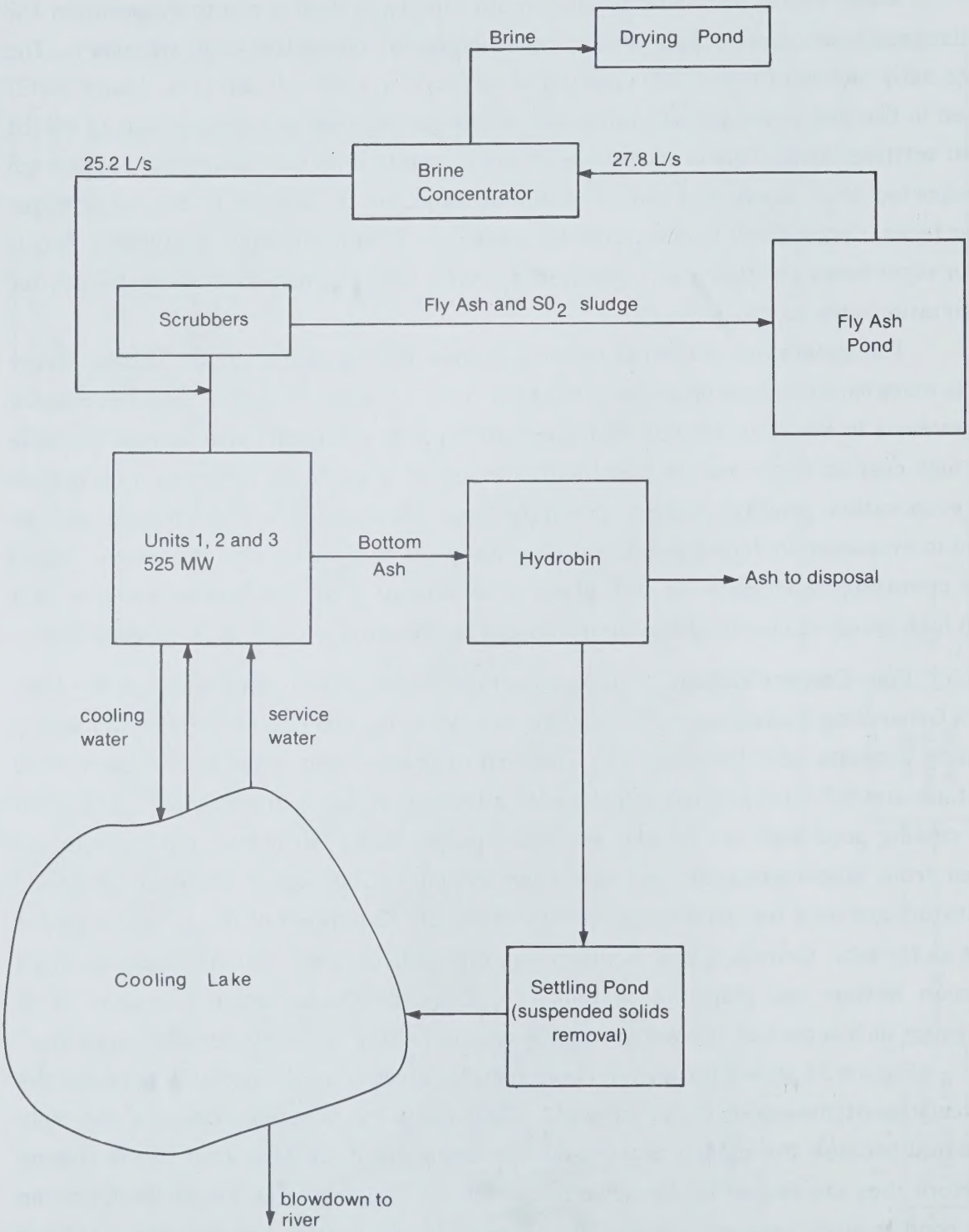


FIGURE 33 FOUR CORNERS GENERATING STATION - WASTEWATER TREATMENT SYSTEM

TABLE 29 WATER BALANCE - FOUR CORNERS GENERATING STATION (34)

Stream Name	Flowrate (L/s)	pH	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Chloride (mg/L)	Carbonate as CO_3 (mg/L)	Sulphate as SO_4 (mg/L)	Sulphite as SO_3 (mg/L)	Nitrate as NO_3 (mg/L)	Phosphate as PO_3 (mg/L)	Silicate as SiO_3 (mg/L)	Suspended Solids (mg/L)
Sluice Tank Feed	64	2.8	790	49	290	11	160	30	2740	8	25	2.2	270	2.2
Ash Pond Overflow	69	9.0	650	64	280	10	180	29	2040	-	23	<0.3	730	<0.01
Make-up; Units 1, 2 & 3	197	8.1	160	40	210	8	110	77	680	-	9	<0.3	100	<0.01
Make-up to transfer tank	129	8.1	160	40	210	8	110	77	680	-	9	<0.3	100	<0.01
Bottom Ash Sluice; Units 1, 2 & 3	40	6.9	160	35	210	8	140	74	690	-	-	<0.3	100	<0.01
Make-up; Units 4 & 5	95	8.1	160	40	210	8	110	77	680	-	9	<0.3	100	<0.01
Bottom Ash Sluice; Units 4 & 5	95	-	-	-	-	-	-	-	-	-	-	-	-	-
Blowdown from Morgan Lake	115	8.1	160	40	210	8	110	77	680	-	9	<0.3	100	<0.01
Make-up to Morgan Lake	940	7.7	55	10	37	2	8.5	1164	117.6	-	1	-	139	-
Bottom Ash Sluice to Ash Pond	25	6.9	160	35	210	8	140	34	690	-	-	<0.1	110	-

The Resource Conservation Company brine concentration unit, which operates as a vapour compression evaporator, is described in Section 6 of this report. This system is integrated into the stack gas scrubbing and fly ash transport systems. Bottom ash is hydraulically removed from the collection hoppers below the boilers and is transported to a hydrobin. The supernatant from the hydrobin is discharged to a settling pond for suspended solids removal. Effluent from the pond returns to Morgan Lake for recycle in the steam units and bottom ash sluicing system.

Recycled effluent from the fly ash pond, at a flow rate of 27.76 L/s, is treated using the RCC concentrator. This unit produces 25.24 L/s of high quality water with 4 mg/L TDS. The concentrated brine is discharged to a drying pond. The high quality water is returned to the air quality control equipment.

The capital cost of the RCC unit was estimated at around US $6 000 000. The system requires 13 kW of connected load and three operators. The major cost savings of the system are associated with the high quality water produced for scrubber system make-up. Without the brine concentrator, the make-up water would have to be treated by expensive physical-chemical means. This incentive is very site-specific and depends on the quality of the raw water supply available to this station.

It becomes difficult to assess the performance of the bottom ash recycle system alone in a station such as this one. The degree of integration of the air quality control systems, ash removal equipment and condenser cooling water flows does not readily allow identification of problems in the system directly due to the recycled ash water system. The bottom ash sluice water has a pH of 6.9 compared to the make-up water, which has a pH of 8.1; the concentrations of calcium, magnesium, sodium, carbonate and sulphate are about the same for the two streams. Based on this the bottom ash sluice water is less likely to form scale than the makeup water supplied to units 1, 2 and 3. Dissolved solids in the system are controlled by blowdown from the cooling lake to the river. The blowdown rate is about 85 percent of the flow rate used to sluice bottom ash from all units. This high rate of blowdown is necessary to maintain the water quality in the cooling lake which is subject to increases in chemical concentrations due to its use for cooling water, plant service water and bottom ash sluicing. The dissolved solids concentration in the blowdown from the bottom ash system is approximately four times that of the make-up to the cooling lake.

4.10 Summary of Bottom Ash Handling Systems

The bottom ash transport systems described in this section of the report are summarized in Table 30. The ash transport systems at these stations were used for either bottom ash only or combined bottom and fly ash.

Six stations had no other waste streams entering the bottom ash system. The water losses from the systems due to occlusion with the bottom ash or by leaks and spills ranged from 0.02 to 1.04 L/min per megawatt. This range reflects differences in both the properties of the bottom ash and the operation of the bottom ash dewatering system.

Two stations used blowdowns to reduce the amount of water present in the bottom ash system. At two other stations, the bottom ash system is integrated with the general plant wastewater system. Because these wastewater systems have a discharge, there is an indirect blowdown from the bottom ash system. In Table 30 the blowdown cited for these two stations is from the plant wastewater system and not the bottom ash system directly.

In only one plant was scaling evident in the system. Analyses of bottom ash transport water in all stations but one showed the water to be stable or to have a theoretical scaling potential. In one case, the Langelier Index predicted that the bottom ash sluice water had a slight corrosion potential; however, there was no evidence of corrosion in the ash system at that plant.

TABLE 30 SUMMARY OF BOTTOM ASH SYSTEMS

Generating Station	Nominal Generating Capacity (MW)	Location	Ash Transport System	Ash Settling Equipment	Other Waste-waters Entering System (L/s)	Water Losses (L/s)	Water Loss (L/min•MW)	Intentional Blowdown (L/s)	Intentional Blowdown (L/min•MW)	Scaling in System
Dunkirk	610	New York	Bottom ash - recirculating	Hydrobin	72	0.7	0.07	0	0	None
Sherburne County	1 360	Minnesota	Bottom ash - recirculating	Lagoon	91.8	8.7	0.38	6.3	0.28	None
Nanticoke	4 000	Ontario	Combined ash - recirculating	Lagoon	All station wastes	22	0.33	100	1.5	None
Sundance	1 350	Alberta	Bottom ash - recirculating	Hydrobin	0	23.4	1.04	0	0	Yes - $CaCO_3$
Dalhousie	212	New Brunswick	Bottom ash - recirculating	Hydrobin	0	0.4	0.11	8.6	2.4	Unknown
Lingan	300	Nova Scotia	Combined ash - recirculating	Lagoon	0	Unknown	Unknown	Unknown	Unknown	Unknown
Boundary Dam	882	Saskat-chewan	Combined ash - once through	Lagoon	0	Unknown	Unknown	-	-	None
Bruce Mansfield	1 700	Pennsyl-vania	Bottom ash - recirculating	Hydrobin/ Lagoon	181	1.0	0.04	101 Lagoon blowdown	3.6	None
Milliken	270	New York	Bottom ash - recirculating	Hydrobin	Unknown	Unknown	Unknown	0	0	None
Centralia	1 400	Washington	Bottom ash - recirculating	Hydrobin/ Lagoon	Plant ser-vice water	Unknown	Unknown	Unknown	Unknown	None
Hayden	460	Colorado	Bottom ash - recirculating	Hydrobin	0	0.12	0.02	0	0	None
Four Corners	2 150	Arizona	Bottom ash - once through	Hydrobin	0	Unknown	Unknown	0	0	None

5.0 FACTORS AFFECTING THE FEASIBILITY OF CLOSED-LOOP BOTTOM ASH TRANSPORT SYSTEMS

During the course of this study, visits were made to nine steam electric generating stations. The design and operating conditions at several other stations described in the literature were also reviewed. At each of these stations, bottom ash is hydraulically removed from a bottom ash hopper. In many cases, the recirculating system had no direct discharge.

These generating stations represent a wide range of operating configurations and nominal generating capacities. Both eastern and western coals were burned and hydrobin or lagoon systems were used. Lagoons were operated either separately for bottom ash disposal or in a combined mode with both bottom and fly ash disposed of in the same system. Generating capacities ranged from slightly over 200 MW per unit to a nominal total station capacity of 4 000 MW. Operating experience covers up to seven years at some installations. Although these systems are designed and operated in a very site-specific manner, some general statements can be made about the design and operation of closed bottom ash transport systems. These are presented in this section of the report.

5.1 Hydraulic Considerations

Operation of a recirculating bottom ash system in a fully-closed mode requires that there be no net accumulation of water in the ash handling system. Any input of excess water must be balanced by losses from the system or else a blowdown or discharge will be necessary.

Excess water inputs to the bottom ash system can come from a number of sources. These include:

- other in-plant wastewaters,
- precipitation and runoff,
- yard wastewaters.

In some of the generating stations visited wastewater streams such as demineralizer wastes, floor drains, boiler blowdowns and coal pile runoff were disposed of in the ash dewatering bins or lagoon. Of the 12 stations described, at least six had other waste streams entering the bottom ash system. In the three stations where data on flows were available, these other waste streams ranged from 4.05 to 6.9 L/min per megawatt.

In the Nanticoke Generating Station, fresh water used for ash sluicing in units 1 and 8, as well as other waste streams entering the lagoon, exceed the water losses from the system. This excessive fresh water usage is due to a pump system problem. However, it appears that if this problem were remedied, the lagoon could receive the other waste streams without a net accumulation of water.

In the Sherburne County and Bruce Mansfield Stations, the other wastewaters entering the lagoon exceed the water losses. At these stations, the excess ash sluice water is used for other purposes in the plant. These water flows allow the bottom ash system to operate with no direct discharge.

Surface runoff can collect in ash lagoons and result in an excess of water. Lagoons in low lying areas are particularly susceptible. The design of the lagoon should ensure that all water entering the lagoon results from the ash sluicing operation. Lagoons should be completely contained with no opportunity for underflow beyond the immediate containment dykes.

Figure 34 shows the areas of Canada where the annual evaporation exceeds annual precipitation. Areas where evaporation equals or exceeds precipitation include southwestern Ontario, most of the prairie provinces and the interior of British Columbia. In these areas, lagoons operating without blowdown will be most feasible because there will be a net loss of water from the lagoons each year.

There may also be large seasonal inputs of water to the lagoon. During the spring runoff water may accumulate and adequate storage capacity must be provided so that the excess water can be used in the system and gradually lost during periods of high evaporation.

An excess of water in the ash transport system can result if significant fresh water is used for such specific operations as refractory cooling, hopper seal water or pump seals.

Normally, recirculated water is used for refractory cooling and for hopper seal water. For example, at the Bruce Mansfield station, high-pressure water used at the bottom ash hopper is recycled at a rate of 107 L/s from the low dissolved solids pond. At the Sherburne County plant, water from the recycle basin is used at 53 L/s for refractory cooling and at 13 L/s for bottom ash hopper seals. In certain designs, fresh water use for these purposes would result in excess water in the system. Fresh water is often used for seals on sluice, flush and seal water pumps, At the Dunkirk Station this water use is 1.6 L/s; however, this is a minor input to the system.

FIGURE 34 AREAS OF CANADA WHERE EVAPORATION EQUALS OR EXCEEDS PRECIPITATION

The major water losses from the bottom ash systems are:

- occlusion in the wet ash for disposal,
- evaporation from the ash hopper,
- use of water for other plant services.

Some transport water is bound to bottom ash as a result of hydraulic sluicing. This occluded water is no longer available to the recycle system and represents a major water loss in a fully-recirculating system.

In hydrobins, the bottom ash is allowed to dewater for a specified period after which it is removed from the system. At the stations visited, removed bottom ash of this type had a moisture content of 10 to 30 percent. The water losses ranged from 0.12 L/s to 23.4 L/s and represented a loss of from 0.02 to 1.04 L/min per megawatt generating capacity.

At some stations, the water content of the bottom ash is minimized as much as possible. For example, the lowest loss rates occurred at the Hayden station, where there is a limited supply of water. At the Bruce Mansfield Station, the bottom ash was taken off-site for ultimate disposal, and when the moisture content exceeded 25 percent, the bottom ash water leaked from the trucks onto the public roads. To prevent this, bottom ash is now dewatered to a moisture content of 10 to 20 percent. At the Sundance station, bottom ash was dewatered to an estimated 25 to 35 percent moisture. At this station, the bottom ash transport and disposal is the responsibility of the coal mining company supplying coal to the station. The bottom ash is removed from the hydrobins by coal hauling trucks and is deposited in the mine spoils area.

The amount of water lost with the bottom ash is related to the operation of the bottom ash hydrobins. At sites where water is not readily available, a drier bottom ash is removed from the station, thus reducing the loss. At plants where make-up water is plentiful and the ash can be removed at a high moisture content, a higher loss rate is evident.

At stations where a lagoon is used for the ultimate disposal of ash, water will be occluded with the settled bottom ash. At the Sherburne County plant bottom ash which settles in the lagoon contains 70 percent water. Water is lost at a rate of 0.38 L/min per megawatt generating capacity by combination with the bottom ash in the lagoon. An estimate of the water lost in this way at the Nanticoke Generating Station is 0.33 L/min per megawatt generating capacity.

These occlusion rates are about the average values for all stations. In lagoon systems, the rate of occluded water is related to the physical properties of the bottom ash, specifically the particle size, surface area and its surface contours. There appears to be a relationship between rates of occlusion and the type of coal burned. The Sherburne County plant burns sub-bituminous coal from Montana and the Nanticoke Station uses a 50/50 blend of Pennsylvania and western Canadian bituminous coals. The occlusion rates are similar for these coal types.

Evaporation can occur at several places in the recirculation system. Some water is evaporated from the bottom ash hopper into the furnace. For example, at the Sherburne County plant 30 L/s or about 14 percent of the recirculated water volume is lost in this way. In radiant dry bottom furnaces, the furnace bottom is shielded from the flooded ash hopper. This reduces the rate of evaporation from the wet hopper.

Evaporation can also occur from hydrobins, settling and recirculation tanks or from lagoons. Estimates of evaporative losses are not widely made but, based on the case histories, this can range from 0.11 to 1.3 L/min per megawatt. At the Dunkirk Station, evaporative losses are estimated at 0.5 L/s. Evaporation from the lagoon at Nanticoke is estimated to be 7.5 L/s. At the Bruce Mansfield Station, evaporation from the low dissolved solids pond is 1.1 L/s.

Excess water from the bottom ash system can be used for other purposes in the generating station. For example, at the Sundance Station, bottom ash sluice water is used to wet fly ash to reduce dust problems during its transportation.

In a properly designed and operated system, it appears that an accumulation of excess water which would necessitate a blowdown should not occur for hydraulic reasons. The volume of water in the system can be maintained by balancing water inputs and water losses.

5.2 Chemical Considerations

Other factors that may result in a blowdown relate to the accumulation of chemical constituents in the ash handling system. These may cause either scaling or corrosion problems. The properties of the bottom ash and transport water which were examined as well as experience at operating generating stations indicates that corrosion is not generally a major problem. Bottom ash transport waters are almost always shown to be stable or to have a tendency to scale rather than corrode. It is unlikely that, under these conditions, a corrosion problem can occur and, for this reason, the formation of scale is of greater importance.

5.2.1 Effect of Recirculation on Water Quality. The recirculation of bottom ash transport water should result in the gradual increase in concentration of some chemical constituents. The example of the Sherburne County plant indicates this. The changes in water quality from January 1977 to December 1978 were presented in Tables 17 to 20, and roughly correspond to the operation of the station from start-up to the present. The total dissolved solids levels have steadily increased from 2 300 to 9 000 mg/L while suspended solids increased from 16 to 44 mg/L. The pH changed very little from 8.7 to 8.4. Of particular interest are the potential scale-forming elements. Calcium increased slightly from 574 to 668 mg/L while carbonate decreased from 42 to 33 mg/L and sulphate increased from 766 to 1 414 mg/L.

Figure 22 showed the same trends in ash lagoon water quality for the Nanticoke Generating Station. At this station, calcium concentrations increased; however, magnesium and bicarbonate remained about the same. The sulphate concentration has increased greatly, about tenfold from 1973 to 1975.

Examination of this data indicates that there is a gradual increase in concentration of some dissolved chemical constituents in bottom ash lagoons. This would suggest that chemical consitutents could eventually surpass the levels believed to form scale. Also, as indicated in the data from the Nanticoke Station, the concentrations of some chemical constituents appear to accumulate more rapidly in combined ash lagoon systems. Fly ash, which is more reactive with water, represents the larger portion of the coal ash and, thus, can greatly affect the lagoon water quality. In the lagoon at Nanticoke, the high concentrations of calcium and sulphate suggest that $CaSO_4$ scale could easily form in the system. It should also be noted that there were chemical inputs in addition to those from the ashes in this particular system.

5.2.2 Effect of Other Wastewaters on Water Quality. Other waste streams entering the bottom ash system can increase the concentrations of the chemical constituents. For example, cationic resin demineralizers can contain sodium sulphate, calcium sulphate and magnesium sulphate, while anionic resin demineralizer wastes can contain sodium sulphate, sodium chloride and sodium silicate. These wastes, when discharged into the bottom ash system, could increase the concentrations of scale-forming minerals. Wastewaters such as coal pile runoff can be very acidic. The addition of this type of waste stream could favourably affect the pH of the bottom ash transport water and reduce the formation of scale; however, a high sulphate content could produce an unfavourable affect.

In combined lagoons, both bottom and fly ash are settled in the same basin. Fly ash has much greater rates of dissolution and requires longer settling times to produce the same quality water. Fly ash transport waters tend to have higher calcium and sulphate concentrations, which could increase the likelihood of scale forming in the bottom ash system.

In theory, the addition of other waste streams to the sluice water recirculation system will generally affect the recirculated water quality adversely. Such waste streams may increase the concentrations of scale-forming minerals which would exacerbate scaling problems. However, at the stations visited, the addition of other waste streams did not always appear to significantly affect the scaling potential of the bottom ash sluice water.

Most of the waste streams other than fly ash sluice water represented a minor component of the total inputs to the systems. As there would be a dilution of these wastes, any changes caused by their addition would not likely be significant. An exception to this would be very acidic waste streams which could affect the water and its scaling potential. At the Nanticoke Station, the disposal of very acidic preheater washing produced a detectable change in lagoon water quality.

In summary, it would appear that in combined ash lagoon systems, large volumes of fly ash sluice water can affect the recirculated water quality by significantly increasing its scaling potential. In such systems, the fly ash properties should be used to design the lagoon retention time and the rate of blowdown. It is less likely that combined lagoons could be operated without scaling problems. Any waste stream that is disposed of in the bottom ash transport system should be characterized to predict the effect of the addition of its chemical constituents.

5.2.3 Effect of Raw Water Quality. If raw intake water is used as a make-up to the bottom ash transport system, the quality of this water may also affect the performance of the bottom ash system. For example, at the Sundance Generating Station, the station raw water had a Langelier Index value of +0.8. This water has a potential to form scale even before it contacts the bottom ash. Similarly, the feed water used to sluice bottom ash at the Boundary Dam Station had a Langelier Index of +0.7. This water also has a theoretical potential to scale. The scaling potential of the make-up water to the ash transport system is particularly important and should be considered in fully recirculating bottom ash systems.

5.2.4 Relative Scaling Rates of $CaSO_4$ and $CaCO_3$. One of the major concerns in operating closed bottom ash systems is thought to be the eventual precipitation of dissolved minerals as scale. Considering the pH of bottom ash transport waters, the most likely minerals to form scale would be calcium carbonate and calcium sulphate.

Analyses of bottom ash transport waters in most generating stations visited showed increased concentrations of Ca^{+2}, CO_3^{-2}, and SO_4^{-2}; however, only one station reported the presence of scale. Analyses from Nanticoke and Boundary Dam showed increases in SO_4^{-2} which are likely associated with fly ash sluicing and at Nanticoke, may also be associated with other inputs. Further, experience at Nanticoke suggests that the theoretical solubility of $CaSO_4$ can be exceeded without the formation of scale.

The formation of $CaSO_4$ scale can be discussed using its solubility product. For sparingly soluble salts, that is those with a solubility of less than 0.01 g-mol per litre, the product of the total molecular concentration of the ions is constant for a constant temperature. This product is the solubility product. If the solubility product is exceeded, then precipitation will occur.

For a binary electrolyte:

$$AB \rightleftarrows A^+ + B^-$$

the solubility product SAB is defined as:

$$SAB = (A^+) \times (B^-)$$

This relationship can be used to explain the absence of $CaSO_4$ scale at the Sherburne County plant.

For $CaSO_4$ calculated solubility product based on the water analysis is:

$$\frac{667}{40 \times 1\,000} \text{ g mol/L } (Ca^{+2}) \times \frac{1\,672}{96 \times 1\,000} \text{ g mol/L } (SO_4^{-2}) = 2.9 \times 10^{-4}$$

For $CaCO_3$, the calculated solubility product for the water is:

$$\frac{667}{40 \times 1\,000} \text{ g mol/L } (Ca^{+2}) \times \frac{9.2}{60 \times 1\,000} \text{ g mol/L } (CO_3^{-2}) = 2.5 \times 10^{-6}$$

The solubility product of $CaSO_4$ at room temperature is 2.4×10^{-5} and for $CaCO_3$ is 4.8×10^{-9} (43).

The calculated solubility products for both $CaSO_4$ and $CaCO_3$ exceed these theoretical values. This suggests that scaling would be a problem due to both minerals. The quantity of expected precipitate can be calculated by taking the square root of the value of the solubility product. For water from Sherburne County, theoretically 1.7 x 10^{-2} g mol/L of $CaSO_4$ and 1.58 x 10^{-3} g mol/L of $CaCO_3$ should precipitate. This suggests that $CaSO_4$ scaling would be more severe than $CaCO_3$ scaling. However, in an ash transport system where Ca^{+2}, SO_4^{-2} and CO_3^{-2} are all present, the calcium would be removed from the water as $CaCO_3$ before $CaSO_4$ would form because of the much lower solubility of $CaCO_3$ compared to $CaSO_4$.

From the theoretical solubility product equation, assuming 667 mg/L of calcium is present, the amount of CO_3^{-2} required to precipitate it can be calculated as follows:

$$\text{g-mol/L } (CO_3^{-2}) = \frac{Ksp\ (CaCO_3)}{\frac{667}{40 \times 100}\ \text{g-mol/L } (Ca^{+2})}$$

$$= 2.9 \times 10^{-7}\ \text{g-mol/L}$$

$$= 17.4\ \text{mg/L } CO_3^{-2}$$

As long as 17.4 mg/L of carbonate is present in the recirculated water, no $CaSO_4$ could form before the formation of $CaCO_3$. Considering the equilibrium between HCO_3^- and CO_3^{-2}, as calcium carbonate is removed by precipitation, the concentration of carbonate ions is replenished from the bicarbonate ions in the water. For this reason, the major concern in closed bottom ash systems should be the prevention of $CaCO_3$ scale rather than $CaSO_4$ scale, as $CaCO_3$ will preferentially form in the presence of small concentrations of bicarbonate and carbonate.

The improtance of the CO_2, HCO_3^{-1}, and CO_3^{-2} equilibrium in the system is evident. Because the transport water is alkaline, carbonate can be present. As long as CO_2 can enter the water, bicarbonate and carbonate can be present, allowing the formation of $CaCO_3$.

As mentioned earlier, CO_2 can be excluded from the lagoon water when a complete ice cover exists over the lagoon and an underwater discharge for the ash water slurry is used. If this situation persisted for a sufficiently long period, all the bicarbonate and carbonate may be removed from the water by precipitation with the calcium in the sluice water. The only source of carbonates would be in the make-up water supplied to

the ash transport system and the only contact between the sluice water and atmospheric carbon dioxide would be in the bottom ash hopper below the boiler. The complete elimination of bicarbonates and carbonates may cause the precipitation of $CaSO_4$. However, there is no known operating experience to suggest that this precipitation occurs.

The possibility of $CaCO_3$ scale can be predicted using the Langelier Index. At all stations but one where this index was used to assess the $CaCO_3$ scaling potential, the values indicated that the water had a slight tendency to scale.

5.2.5 Effect of Winter Operation on Scaling. Operation of a lagoon in winter conditions could affect the transport water quality. In theory, an ice cover on the lagoon could prevent CO_2 from the atmosphere from entering the alkaline lagoon water. This could have two effects. The pH of the water can be maintained at high levels since the carbon dioxide cannot react with alkalinity in the water. This would tend to favour scaling. Conversely, if no CO_2 can enter the water, then no carbonate can be formed. This could prevent the formation of $CaCO_3$ scaling. Based on data from the Nanticoke Station, the calcium carbonate concentration is slightly higher in the winter which indicates that the first effect is greater. Assuming operating conditions similar to those at Nanticoke existed at a station where an ice cover persisted on a lagoon for extended periods, there would, theoretically, be higher rates of scaling. This effect would also be greater if the ash slurry was discharged below the surface of the lagoon since there would be no contact between the sluice water and the atmosphere.

Experience at Nanticoke indicates that only minor changes in water quality are attributable to the presence of a lagoon ice cover. At this station, the operation of a lagoon in winter does not appear to greatly affect the water chemistry of the system.

5.2.6 Effect of Preferential Precipitation on Scaling in the Transport System. The lack of evidence of calcium carbonate scale in bottom ash water recirculating systems can be explained by examining what happens to the transport water as it makes one cycle through the system. The water in the recirculation system is warmest when it is in the bottom ash hopper and in the overflowing weir. At this higher temperature, the main scaling minerals, $CaCO_3$ and $CaSO_4$, are least soluble and would likely precipitate out of the water. The scaling minerals would tend to precipitate mainly on suspended solids in the sluice water by the process of preferential precipitation.

In this process, calcium carbonate and calcium sulphate scales form by crystallizing out of the solution. They do not form entrained solid particles directly. Crystallization takes place on a solid surface. This can be the hot metal surface of the

hopper or pipes or any other solid surface such as suspended particulates. During preferential precipitation dissolved calcium would tend to crystallize primarily on solid particles in the sluice water rather than on heat transfer surfaces because the suspended solids provide a significantly greater surface area for the precipitation of scale to occur. This crystallization process will occur if the water is sufficiently heated, solids are present, and enough time is allowed for the reaction to take place. Crystallization depletes the transport water of the soluble scale-forming calcium compounds and reduces scaling in the rest of the system. The soluble calcium remaining in the water is a useful indicator of scaling potential; however, it is not necessary to reduce the soluble calcium to zero to eliminate scaling.

This concept is used in the paper industry to evaporate calcium-rich liquors without scaling. In this case, calcium carbonate is added to the liquor to provide suspended solids to act as precipitation sites (44).

As the sluice water continues through the bottom ash transport system, there is further opportunity for preferential precipitation to occur. However, as the sluice water cools the solubility of $CaCO_3$ and $CaSO_4$ increase, reducing the rate of the precipitation. When the transport water is in the ash settling equipment, the temperature is at its lowest in the system. In winter the water temperature can approach 0°C. At this point in the system, the scaling minerals are at their highest solubility.

The principle of metastable solubility can be used to explain the absence of scaling in the return side of recirculation systems. This concept can be explained by examining the relationship between solubility and temperature as shown in Figure 35. Curve A shows the solubility at equilibrium for the scaling mineral. Below this curve, no precipitation and hence no scaling can occur because the solubility has not been exceeded. Curve B lies within the metastable region. Supersaturation can occur if the water is not disturbed. The formation of new crystals with resulting precipitation will not occur. Curve C is the upper boundary of the metastable region. Above this curve, crystal nuclei will form so readily that there is no unstable saturation area. This relationship shows that the solubility can be exceeded and a super-saturated solution can exist without the formation of a precipitate. This principle allows an additional margin of safety in the transport water which allows the solubility to be exceeded without the formation of a scale.

This metastable region has been shown to exist for both calcium carbonate and magnesium hydroxide (34). Figure 36 shows that the precipitation rate of $CaCO_3$

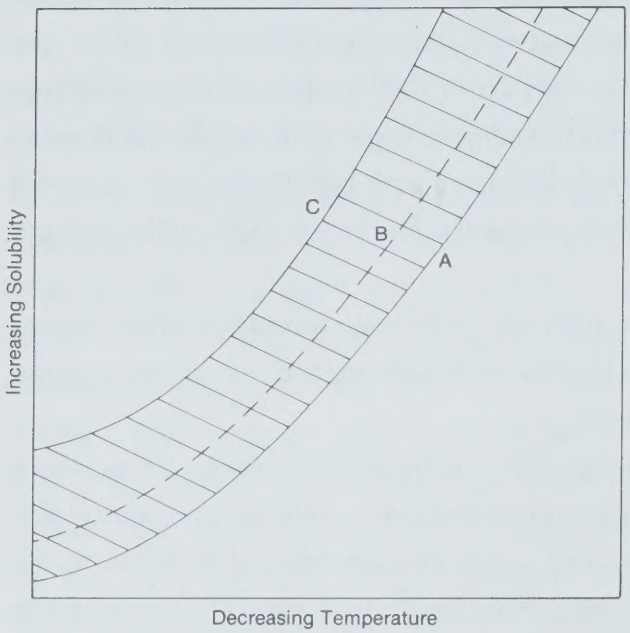


FIGURE 35 THE PRINCIPLE OF METASTABLE SOLUBILITY (44)

A Solubility curve at equilibrium
B Line within the metastable region
C Boundary above which there can be no supersaturation

increases at a constant rate from a relative solubility of 1.00 to 2.60. At this point the precipitation rate greatly increases. This corresponds to crossing the metastable region and surpassing curve C on Figure 35.

This helps to explain why a transport water can exceed the solubility of a given scaling mineral without evidence of any scaling. For example, the solubility of $CaCO_3$ can be exceeded by 2.5 relative saturations and still be in the metastable region without any precipitation occurring.

Regardless of the type of ash settling equipment used, all the suspended solids cannot be removed. The very small diameter particles have very long settling times and

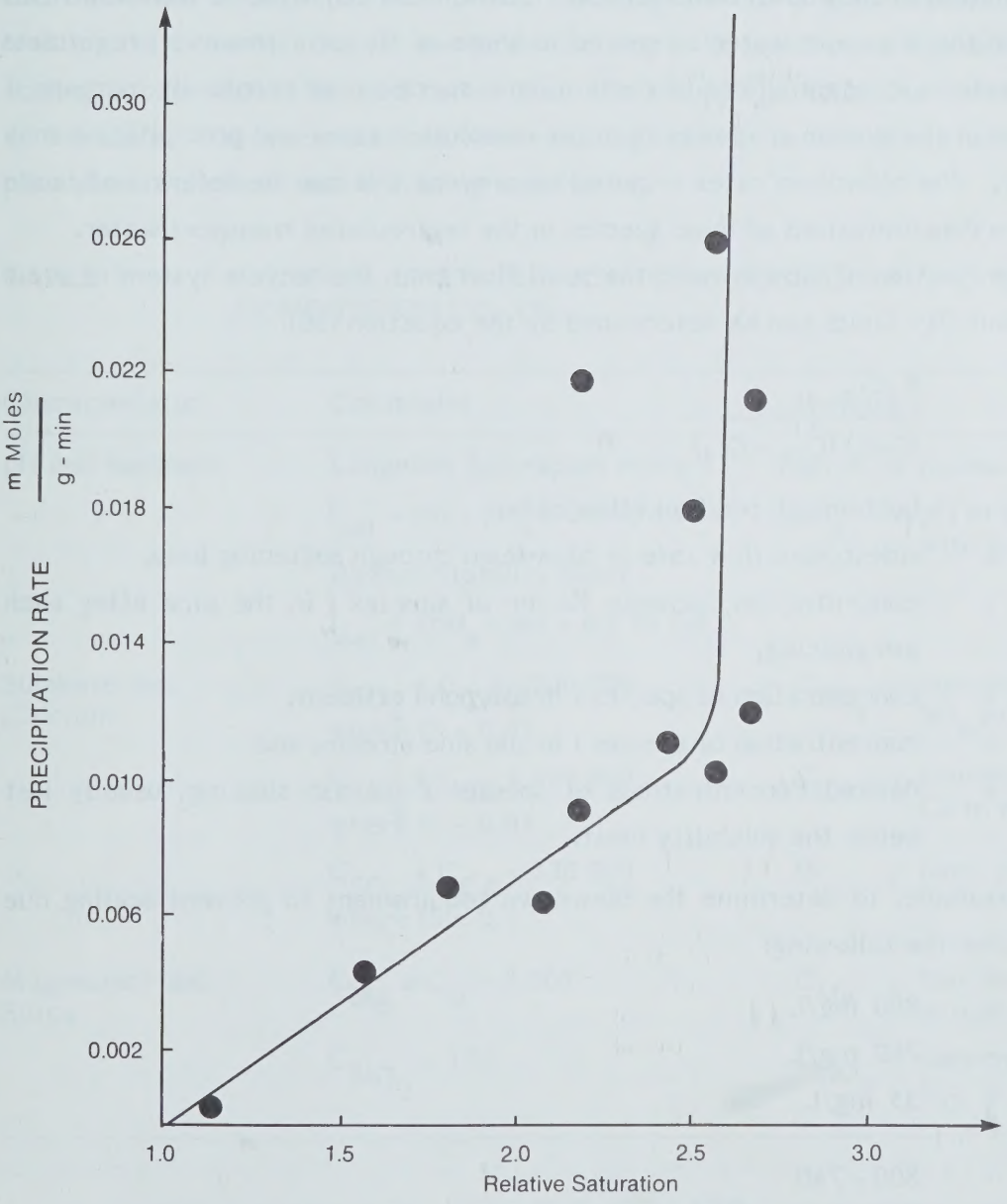


FIGURE 36 $CaCO_3$ PRECIPITATION KINETICS (34)

the water movement would likely entrain some solids in the return lines for the ash transport water. The presence of these solids makes preferential precipitation sites available so that, even if the metastable region was exceeded, scale would tend to form on the suspended solids rather than on the metal surfaces of the ash water equipment.

5.2.7 Estimation of Blowdown Requirement. Bottom ash constituents have low rates of dissolution into the transport water compared to those of fly ash. However, regardless of how low the rate is, concentrations of certain ionic species may eventually increase if the removal rates in the system are lower than the dissolution rates and precipitation may eventually occur. The blowdown rates required to prevent this can be determined based on the acceptable concentrations of ionic species in the recirculated transport water.

The proportion of blowdown to the total flow from the recycle system to avoid exceeding the solubility limits can be determined by the equation (30):

$$\frac{Q_3}{Q_2} = \frac{K_i Ci_2}{(1+k_i)(Ci_2 - Ci_3)}$$

where:
- Q_2 = bottom ash pond overflow rate,
- Q_3 = sidestream flow rate or blowdown through softening loop,
- k_i = concentration increase factor of species i in the pipe after each ash sluicing,
- Ci_2 = concentration of species i in ash pond effluent,
- Ci_3 = concentration of species i in the side stream, and
- Ci_4 = desired concentrations of species i for ash sluicing, usually just below the solubility limit.

For example, to determine the blowdown requirement to prevent scaling due to mineral i, assume the following:

Ci_2 = 800 mg/L
Ci_4 = 740 mg/L
Ci_3 = 35 mg/L

then: $$K_i = \frac{800 - 740}{740} = 0.08$$

then: $$\frac{Q_3}{Q_2} = \frac{(0.08)(800)}{(1 + .08)(800 - 35)} \times 100 = 7.7\%$$

For this example, the required blowdown to prevent scaling of the element is 7.7 percent of the total flow.

The control limits for the quality of recirculated bottom ash water are shown in Table 31. These control limits are very general; however, they can be used to estimate the blowdown requirements to prevent scaling due to a given scale-forming mineral. Ideally, the concentration of the scale-causing ionic species at the actual point where scaling occurs should be used rather than the theoretical solubility concentrations shown on the table. The concentrations where scaling actually occurs should be determined from pilot plant work or actual operating experience.

TABLE 31 CONTROL LIMITS FOR ASH POND RECIRCULATING WATER COMPOSITION (30, 39)

Characteristic	Constraint	Remark
pH and hardness	Langelier Saturation Index	pH = measured pH
	$I_{sat} = pH - pH_s = 0.0$ to 1.0	pH_s = pH at saturation with $CaCO_3$
	Ryznar Stability Index	
	$I_{sat} = 2pH_s - pH = 6.0$ to 7.0	
Sulphate and Calcium	$C_{SO_4} \times C_{Ca} = 200\,000$ where IS = 0.01	C_{SO_4} = concentration of SO_4 in mg/L
	$C_{SO_4} \times C_{Ca} = 460\,000$ where IS = 0.05	C_{Ca} = concentration of Ca in mg/L
	$C_{SO_4} \times C_{Ca} = 730\,000$ where IS = 0.1	IS = ionic strength
Magnesium and Silica	$C_{Mg} \times C_{si} = 8\,505$	C_{Mg} = concentration of Mg in mg/L
	$C_{SiO_2} = 150$	C_{siO_2} = concentration of Si_{O_2} in mg/L

Where a blowdown is required, some other reuse of the water or treatment would probably be necessary. Alternatives for the handling of blowdown are discussed in Section 6 of this report.

5.3 Site-Specific Conditions

Recirculating bottom ash systems exist in a number of configurations and are operated in a variety of modes. During the site visits several design and operational problems were identified which warrant discussion.

5.3.1 System Sizing. An important consideration is the sizing of the bottom ash handling system. The operation and sizing of hydrobins for ash dewatering is directly related to ash production rates and ash settling properties. In the design stage of the system, certain parameters which form the basis of the specifications for the hydrobins and pumps result from preliminary test burns and analyses of the expected fuel coal. Coal is inherently variable and the fuel supplied to a station can also change over its lifetime. This can cause an overloading of the ash removal system, and this problem is particularly pronounced in a hydrobin dewatering system. Because the bin capacities and settling rates are essentially fixed, a greater loading on the system will result in a higher moisture content in the bottom ash removed from the bin. Excessive loadings will also cause higher levels of solids to be carried in the transport system.

To prevent problems due to the undersizing of hydrobin equipment, accurate data must be available from test coal burns and it must be used in the specification of equipment in the system. The small cost penalty of selecting hydrobins that provide a factor of safety may well be justifiable in view of reduced operation and maintenance costs during the lifetime of the system.

5.3.2 Winter Operation of Hydrobins. Early bottom ash system designs did not fully consider the operating problems that could develop during cold weather. Systems where hydrobins have a long dewatering period and where water is allowed to stand in the transfer piping are particularly susceptible.

Severe problems can be encountered during winter operation due to freezing of pipes outside the plant, especially around the dewatering bins. The gates that discharge the dewatered ash can become inoperative. It is important that consideration be given to adequately prevent freezing of components of the system. This may necessitate the insulation and heat tracing of sluicing lines outside the station. These lines should also be self-draining to prevent the accumulation of water when the lines which may freeze are not operating. It may be necessary to heat the hydrobins, particularly in the gate valve area, or confine them in the heated enclosure.

5.3.3 Bottom Ash Abrasion. The most widely-encountered problem with bottom ash systems is the abrasive erosion of system components by the bottom ash. This problem was mentioned in a majority of the stations visited. However, abrasion is not limited to generating stations with recirculating systems. Any plant using a hydraulic sluicing system for removal of bottom ash can experience this problem. The problem is manifested by progressive mechanical erosion which causes the eventual failure of bottom ash sluice pumps and transport bins, pipes and valves.

The bottom ash that results from the combustion of coal can be physically characterized as being glass-like and angular. The ash particles, when sluiced through jet pump venturis and transport lines, wear away the metal. Several options exist to reduce this problem. Harder alloys can be specified in the system design. Brinnell hardness numbers of 500 to 550 can be specified for most components supplied by the major vendors. Fittings that can be reversed can effectively double the service life. Experimental use of high-density plastic pipe has been considered; however, the most resistent piping currently available is basalt-lined. This is very expensive and must be shop fabricated but provides the longest service life. Transport piping can also be rotated, typically 90 degrees per year. This distributes the erosion around the pipe and provides a longer service life.

One generating station which sluices bottom and fly ash through parallel lines alternates the flow of bottom and fly ash in each line. This has two advantages. The abrasion of the bottom ash is distributed over two pipes and the abrasive bottom ash tends to remove the accumulation of scale in the fly ash sluice lines.

6 BLOWDOWN HANDLING ALTERNATIVES

Due to site-specific problems associated with ash handling system hydraulics, water chemistry problems, or mechanical limitations, it may not be possible to operate a recirculating transport system without some blowdown.

Three options exist for the handling and disposal of blowdowns. These are:

a) cascade water use,
b) sidestream treatment,
c) effluent treatment.

6.1 Cascade Water Use

The cascade concept of wastewater reuse, i.e., using lower quality wastewater in plant processes not requiring high quality water, has been reported at one generating station (45). Using this method, the volume of ash transport water blowdown requiring treatment or discharge to the receiving waters can be considerably reduced and even eliminated depending onthe areas available to reuse this waste stream.

Desulphurization scrubber systems are one potential area where ash system blowdown could be reused (46). This air quality control system requires large amounts of make-up water since the waste sludges are removed at high moisture contents. Water is also lost from the system due to evaporation, entrainment, and chemical reaction. Any limestone-rich water can be used in the scrubber system; however, because of its impurities, ash pond water may be less suitable for this use than demineralizer wastes or cooling tower blowdown.

Blowdown from the bottom ash transport system can also be used for dust suppression. For example, when fly ash is removed from some stations by truck, the ash is sprayed with water to reduce the fly ash dust during transport. Since the quality of this water is unimportant, blowdown from the bottom ash system could be used.

Other possible uses for blowdown include coal pile cooling and coal pile dust suppression. In 1977, 3.6×10^3 m^3 of water from Lake Erie was used for dust suppression on the coal piles at the Nanticoke Generating Station. Blowdown from the ash system could be used for this operation, which would reduce the volume of blowdown presently discharged.

Cascade water use may require storage of blowdown and pumping the water to the location in the plant where it will be used. The ash transport system may have a

continuous blowdown while the water may be required only intermittently. A storage tank to accumulate the blowdown between uses and lines to transport the blowdown from its source to its point of use would be necessary.

6.2 Sidestream Treatment

Sidestream treatment of blowdown from the bottom ash transport system can be used to reduce the concentrations of scaling minerals. In this system, a portion of the blowdown from the ash transport system is treated and returned to the main stream as make-up. This approach is economically attractive because only a portion of the total recirculated water is treated to remove only the contaminants that limit its ability to be recycled. These would include carbonate and noncarbonate hardness in bottom ash transport water blowdowns. The scaling minerals are removed from the waste streams in the treatment process and the ash handling system can be operated in a zero hydraulic and contaminant discharge mode.

Several treatment systems can be used to eliminate the chemical constituents responsible for scaling in the blowdown from ash sluice waters. These include:

a) Lime-soda softening
b) Membrane processes
c) Ion exchange
d) Evaporation

6.2.1 Lime-Soda Softening. Lime-soda softening is widely used for the removal of calcium and magnesium salts from process waters by chemical precipitation. The treatment involves the use of lime (calcium hdyroxide) and soda ash (sodium carbonate). In the process, hydrated lime, which forms when calcium oxide contacts water, chemically precipitates the carbonate hardness in the water. Insoluble precipitates of calcium carbonate and magnesium hydroxide are formed without the production of soluble by-products. These suspended precipitates are removed by sedimentation and/or filtration. Soluble species such as calcium sulphate and calcium chloride which constitute the calcium non-carbonate hardness must also be removed. These chemical species are precipitated as calcium carbonate by the use of soda ash (sodium carbonate).

The lime-soda softening process is well-suited for the removal of chemical constituents which would be present in blowdowns from bottom ash transport systems. It can be used in a sidestream mode. The technology is well-proven and economically attractive. Lime-soda softening has been investigated for use in a side-stream softening

mode to treat bottom ash system blowdowns. Figure 37 shows a sidestream softening closed-loop ash pond system. In this system, a portion of the recycled transport water is treated using lime-soda softening and returned to the main recycle flow for repeated sluicing of bottom ash.

In a simulation study (30), it was found that soda ash alone could reduce the calcium concentrations sufficiently to reduce scaling problems due to the presence of high carbonate hardness and high pH values. Additions of excess lime could significantly reduce sulphate concentrations in the ash sluice water.

In a detailed study Velez et al (47) investigated the use of lime-soda softening to remove the chemical constituents in bottom ash sluice water that would limit it for recycle. They found that the concentrations of sulphate and $CaCO_3$ increase with increasing concentrations of bottom ash in the sluice water. Jar testing of the lime-soda softening process indicated that, with an addition of 1 000 mg/L of $Na_2CO_3 \cdot H_2O$, about two-thirds of the total hardness was removed. The actual hardness removal rates slightly exceeded the stoichiometric projections. Sulphate reductions were limited to 21 percent at a lime dosage of 2 000 mg/L. The addition of soda ash at 2 000 mg/L did not significantly affect the sulphate reductions achieved by the addition of excess lime. It can be concluded that soda ash alone could reduce calcium concentrations to those necessary to control scaling due to high pH and non-carbonate hardness. For the ash transport water investigated, 90 percent of the total hardness could be removed in about 110 minutes (47).

Chu et al (30) identified pH, alkalinity, ionic strength, temperature and concentrations of calcium, magnesium, sulphate and bicarbonate as important variables in lime-soda softening of ash pond effluents. Lime-soda softening of ash pond effluents removed approximately 90 percent of the turbidity by the first stage of lime clarification and the sludge settled within ten minutes. The removal of trace metals was pronounced at a pH of greater than 7.5.

Lime-soda softening is a well-proven method to treat process waters. It has the advantage that it removes the scaling minerals of greatest concern in recirculating bottom ash systems. A further benefit is that the softened water produced from the process may be of higher quality than the station's raw water supply. This would be particularly true in Western Canadian situations where the surface water is characteristically hard. The reuse of this softened water in the recirculation would favourably affect the water chemistry of the system.

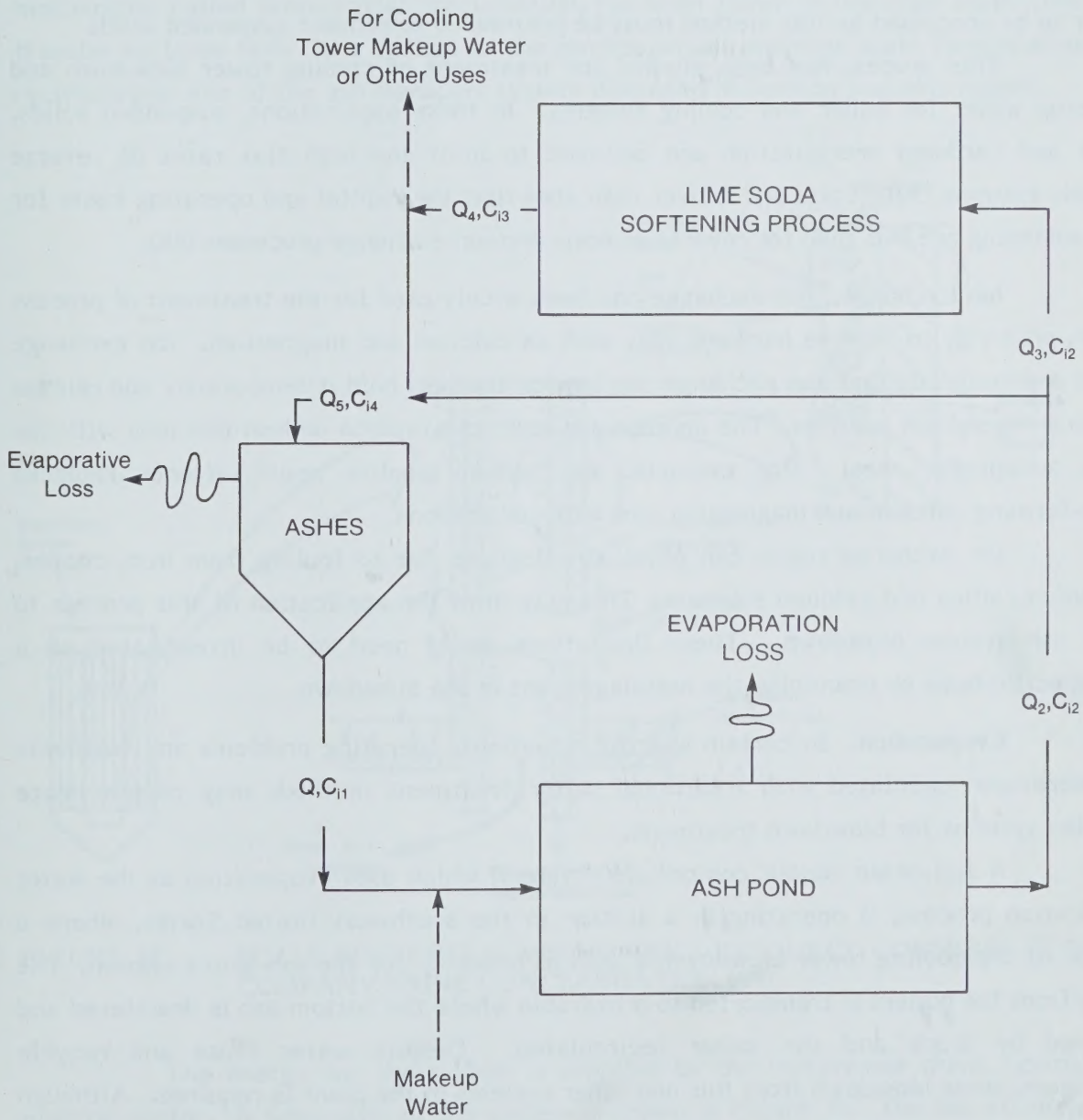


FIGURE 37 SIDESTREAM SOFTENING CLOSED-LOOP ASH TRANSPORT SYSTEM (30)

6.2.2 Membrane Processes. Reverse osmosis is a membrane process which uses pressure as a driving force to transport a solvent from a concentrated to a less-concentrated stream through a semi-permeable membrane. This system can be described as a high capital cost, high energy process and, due to membrane replacement, it also has a high maintenance cost. Because of fouling problems with the membrane, water to be processed by this method must be pretreated to remove suspended solids.

This process has been studied for treatment of cooling tower blowdown and make-up water for boiler and cooling systems. In these applications, suspended solids, silica and hardness precipitation are believed to limit the high flux rates of reverse osmosis systems (30). Crits and Glover indicated that the capital and operating costs for lime softening are less than for reverse osmosis and ion exchange processes (48).

6.2.3 Ion Exchange. Ion exchange has been widely used for the treatment of process water, primarily to remove hardness ions such as calcium and magnesium. Ion exchange resins are materials that can exchange one ion for another, hold it temporarily and release it into a regenerant solution. The appropriate resin can replace undesirable ions with far more acceptable ones. For example, the sodium zeolite resin softener replaces scale-forming calcium and magnesium ions with sodium ions.

Ion exchange resins can physically degrade due to fouling from iron, copper, aluminium, silica and calcium sulphate. This may limit the application of this process to treat ash system blowdown. These limitations would need to be investigated on a site-specific basis by examining the metals present in the blowdown.

6.2.4 Evaporation. In certain specific situations, operating problems and economic considerations associated with traditional water treatment methods may require more complex systems for blowdown treatment.

A full-scale vapour compression system, which uses evaporation as the water purification process, is operating in a station in the southwest United States, where a portion of the cooling tower blowdown is used as make-up for the ash slurry system. The slurry from the boilers is transported to a hydrobin where the bottom ash is dewatered and removed by truck and the water recirculated. Despite water reuse and recycle techniques, some blowdown from this and other systems in the plant is required. Although softening, reverse osmosis, and other treatment methods were considered, a vapour compression evaporator or brine concentrator was selected for use (49).

The brine concentrator used at this plant and at several others (50) is a long-tube, vertical, falling film evaporator using a vapour compression cycle. During the

evaporator's operation, as shown in Figure 38, water is evaporated inside the tubes as steam. The remaining brine film becomes supersaturated and typically calcium sulphate and silica start to precipitate. The precipitating material promotes crystal growth in the slurry rather than new nucleation that would deposit on the heat transfer surfaces. Silica crystals attach themselves to the calcium sulphate crystals. This scale prevention mechanism, called preferential precipitation, has been shown to maintain scale-free heat transfer surfaces (49). It is similar to the process which prevents scale formation on the recirculation side of the ash transport system discussed in Section 5 of this report.

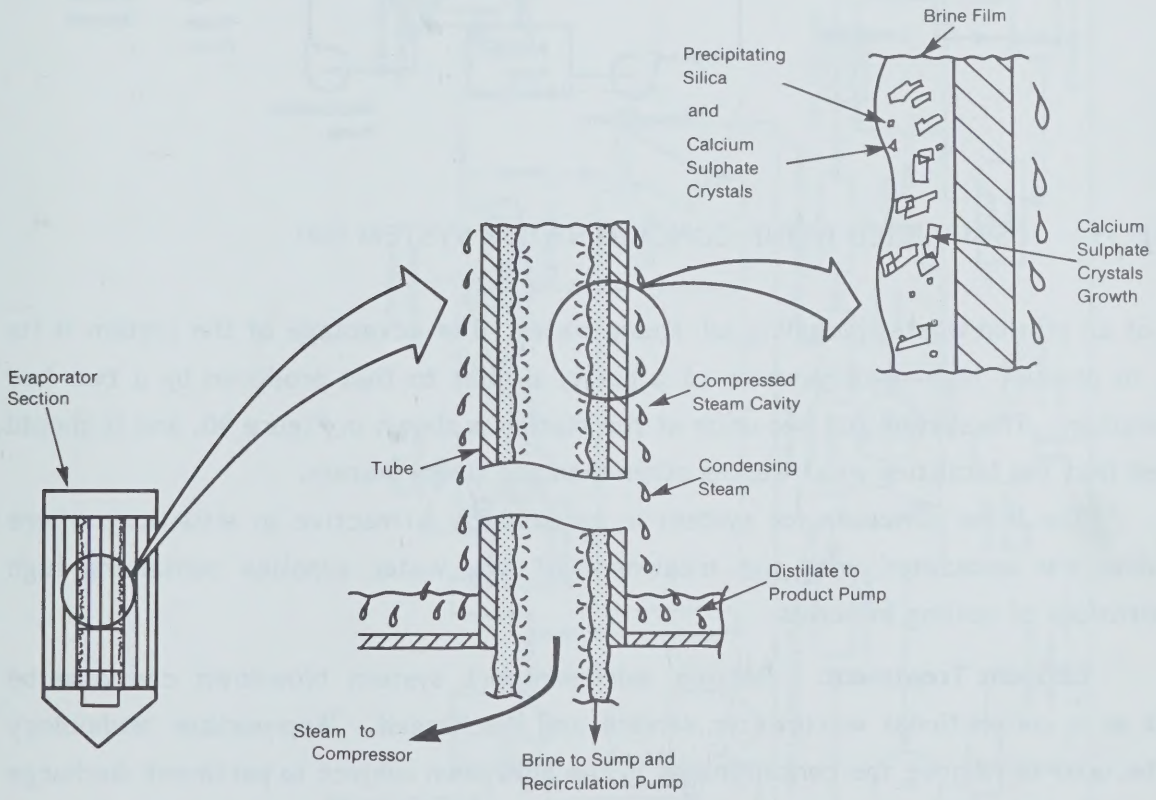


FIGURE 38 SCALE PREVENTION MECHANISM - RESOURCE CONSERVATION COMPANY BRINE CONCENTRATION (49)

The energy for the system is supplied by the compressor drive, normally an electric motor. A schematic of the system is shown in Figure 39. The hot effluent from the system can be pumped back through a heat exchanger and recycled to the power station at less than 10 mg/L TDS. Normally, 90 to 96 percent of the influent is discharged as treated effluent with low TDS. The system is suggested for application in closing the

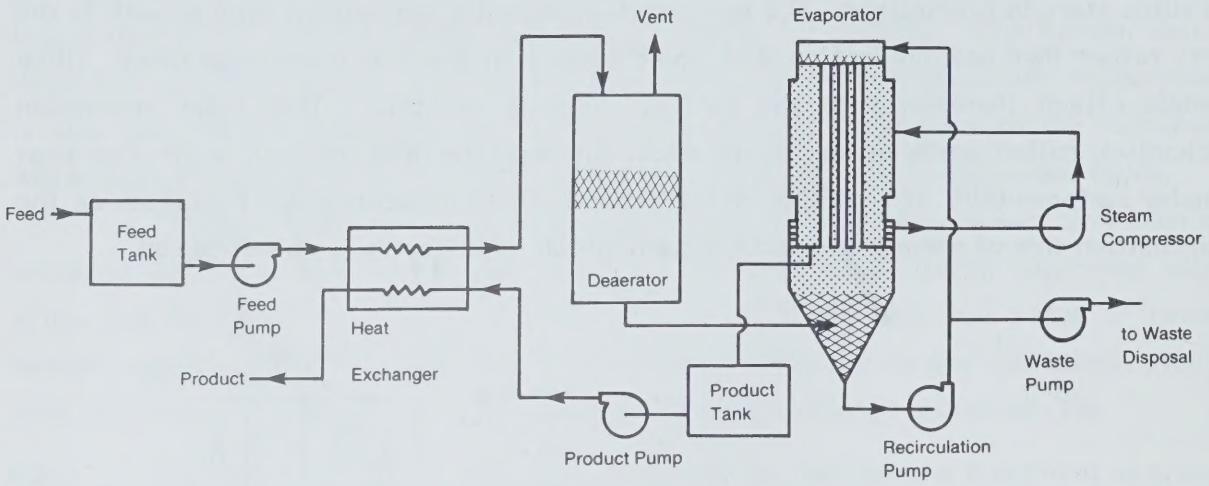


FIGURE 39 SIMPLIFIED BRINE CONCENTRATOR SYSTEM (49)

cycles of all station wastes including ash sluice water. The advantage of the system is its ability to produce high-quality water of a purity similar to that produced by a two-bed demineralizer. The system for two units at the station is shown in Figure 40, and it should be noted that the facilities treat wastes other than ash sluice waters.

The brine concentrator system is particularly attractive in situations where high costs are associated with the treatment of raw water supplies containing high concentrations of scaling minerals.

6.3 Effluent Treatment. Bottom ash transport system blowdown can also be treated as a conventional wastewater stream and discharged. Appropriate technology would be used to remove the contaminants in the blowdown subject to pertinent discharge regulations. In this case zero discharge of contaminants might be approached, depending on the treatment efficiency, but there would still be a hydraulic discharge if the treated blowdown were not recovered for reuse in the ash transport system.

If a comparable reduction in the total amount of contaminants discharged were to be achieved, this option would be the least cost efficient because large volumes of water would have to be treated to reduce concentrations of suspended solids and metals and pH adjustment might also be required. The wastewater treatment system would also be subject to modification to meet new water quality objectives as they were established.

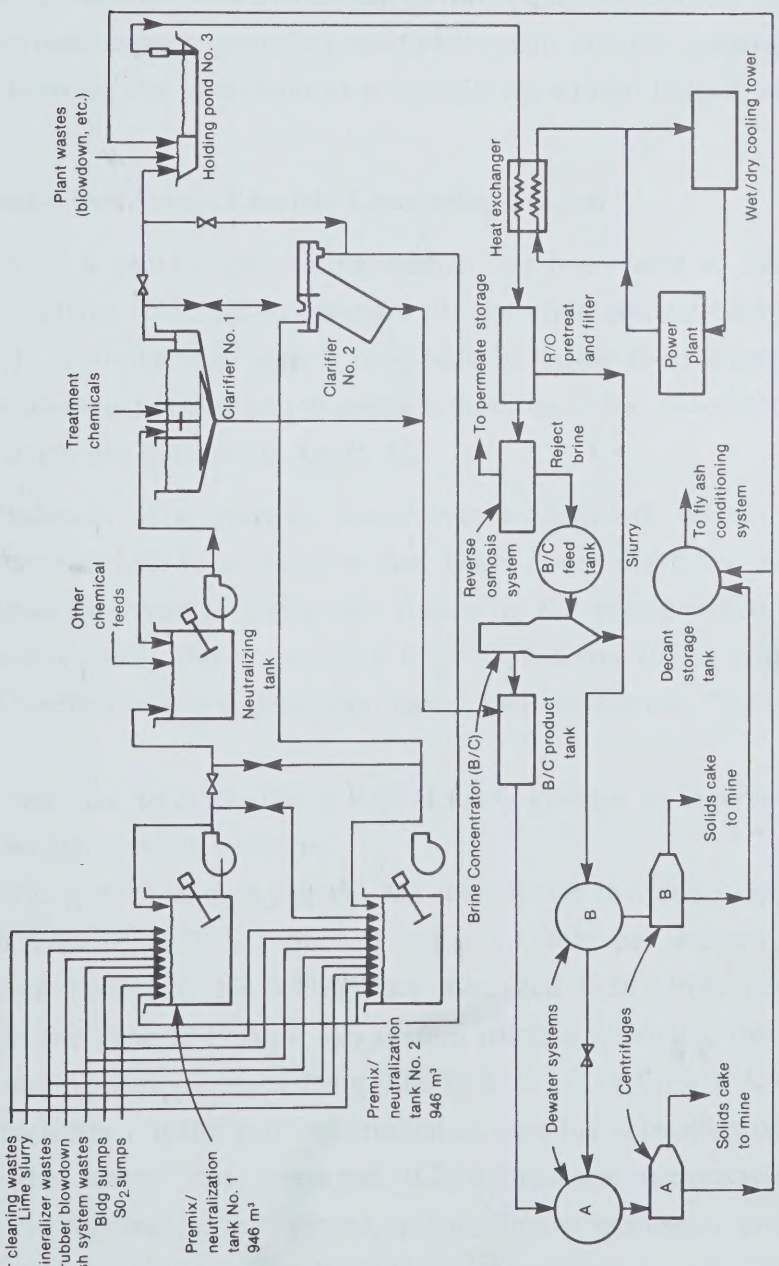


FIGURE 40 INTEGRATED WATER-RECYCLE SYSTEM, UNITS 3 AND 4, SAN JUAN GENERATING STATION (50)

This option is least acceptable from an economic, environmental and water use perspective. Although suspended solids can be readily removed by flocculation-clarification or filtration, major problems would be encountered with the removal of comparable quantities of heavy metals. Complex treatment systems would be necessary due to the wide variety of metals present at relatively low concentrations in the blowdown.

7.0 SUMMARY AND CONCLUSIONS

Experience at several coal-fired steam electric generating stations that have operated fully-recirculating bottom ash transport systems for a number of years has shown that, in many cases, these systems can achieve zero discharge without sidestream treatment to control the accumulation of scale-forming minerals. Several site-specific factors influence the feasibility of zero-discharge recirculating bottom ash systems. These can be best described using a generic coal-fired steam electric generating station to define the factors limiting the operation of a completely-closed bottom ash transport system.

7.1 Generic Coal-Fired Steam Electric Generating Station

The concept of a generic generating station has been used to identify water recycle and reuse alternatives (24), and to compare air pollution control devices in power generating stations (51). A similar approach is used here to define the factors influencing the feasibility of closed-loop bottom ash transport systems. The assumptions used in defining the generic station are outlined in Table 32.

7.1.1. Hydraulic Balance. The generic closed-loop bottom ash system is shown in Figure 41. A hypothetical hydraulic balance has been determined for each of five representative coal types as shown in Table 33. Assuming the precipitation received by the ash settling equipment equals the evaporation ($Q_6 = Q_5$), water losses in hydrobin and lagoon systems due to occlusion and evaporation have been estimated. These are shown on Table 34.

The water loss due to occlusion is significantly greater in lagoon ash settling systems than in hydrobin ash settling systems.

In the generic system using a lagoon, the total water loss due to quenching and occlusion ranges from 1.25 to 10.05 L/s or 0.19 to 1.51 L/min per megawatt. In the stations studied as case histories this water loss averaged 0.36 L/min per megawatt generating capacity. In the generic bottom ash system using a hydrobin, the total water loss due to quenching and occlusion ranges from 0.86 to 6.92 L/s or 0.13 to 1.04 L/min per megawatt generating capacity. In the stations studied as case histories that used hydrobin dewatering systems, the water loss averaged 0.26 L/min per megawatt generating capacity. The water loss rates in the generic plant due to occlusion and quenching compare favourably to those values noted in operating stations.

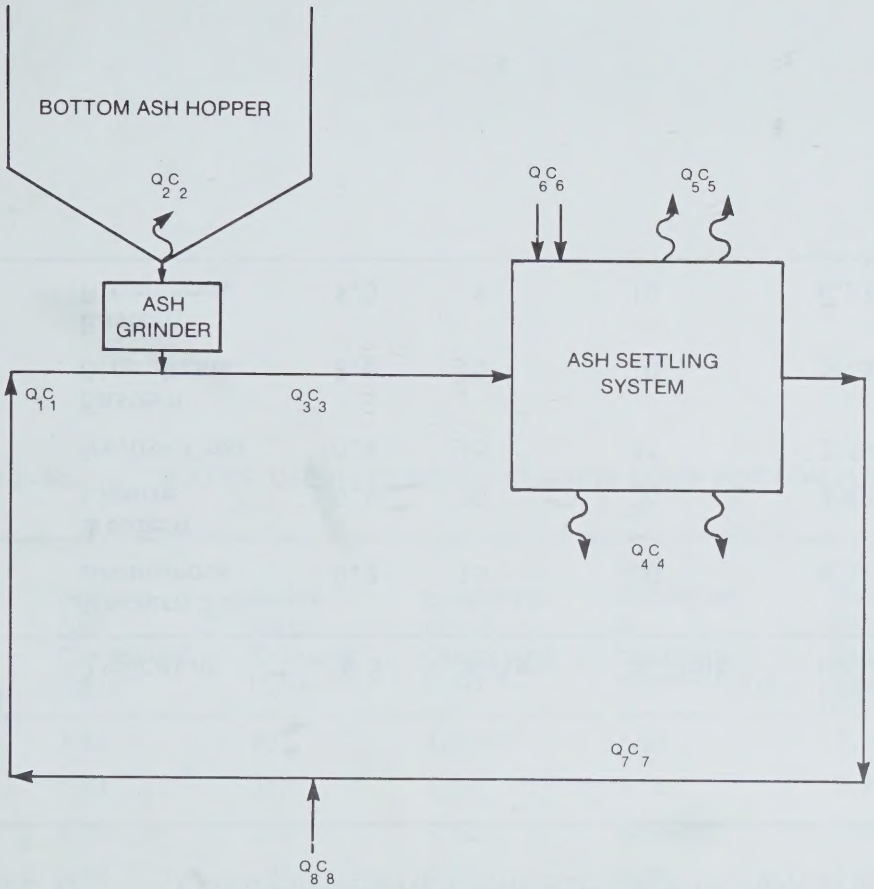
TABLE 32 POWER PLANT CHARACTERISTICS ASSUMED FOR A GENERIC PLANT

- 400 MW gross generating capacity - 65% of load factor	
- Pulverized coal feed to tangentially-fired boiler	
- Fly ash to bottom ash ratios of 75:25	
- Bottom ash handling system	- 1 percent solids for sluicing (99 000 L/tonne of bottom ash)
	- 650 L/tonne of bottom ash evaporation loss in quenching process.
	- 540 L/tonne occluded moisture in bottom ash when settled in a hydrobin system (35 percent moisture content in dewatered bottom ash).
	- 1 080 L/tonne occluded moisture in bottom ash when settled in a lagoon system (70 percent moisture content in dewatered bottom ash).

From a hydraulic balance perspective, there is a make-up requirement in hydrobin-based systems, of about 1.2 percent of the sluice water flow. In a lagoon-based system, about 1.7 percent make-up is required to maintain the water balance. All other sources of water in the bottom ash system must be less than these make-up rates to prevent the accumulation of excess water in the system.

The generic plant description represents the minimum water losses and make-up requirements in the operation of a bottom ash transport system. It is evident that there is a net loss of water from the system of between about one and two percent of the recirculation rate in the ash transport system if no additional wastes enter the system. Thus, under these conditions, no intentional discharge is necessary to maintain a hydraulically-balanced system. If other more or less continuous flows entering the system exceed this loss, a net accumulation of water will result and some discharge will be necessary.

7.1.2 Chemical Considerations. Based on the hydraulic balance of the generic generating station, there will be a one to two percent make-up to the ash transport system. This make-up water will dilute the recirculated water and reduce its tendency to



LEGEND

Q_xC_x	Flow rate of stream x which has a concentration of chemical constituents of x
Q_1C_1	Recirculated bottom ash sluice water
Q_2C_2	Evaporation of bottom ash hopper water into furnace
Q_3C_3	Bottom ash and transport water slurry
Q_4C_4	Water occluded with bottom ash
Q_5C_5	Evaporation from ash settling equipment
Q_6C_6	Precipitation received by the ash settling equipment
Q_7C_7	Overflow from ash settling equipment
Q_8C_8	Makeup water supplied to the recirculation system

FIGURE 41 GENERIC BOTTOM ASH TRANSPORT SYSTEM

TABLE 33 COAL PROPERTIES AND ASH PRODUCTION FOR TYPICAL DESIGN COALS (51)

Coal No.	Typical of	% S	% Ash	% Mois.	Heat Value (MJ/kg)	Coal Usage (kg/s)	Ash Production (400 MW, 37% Gross Efficiency)	
							Fly Ash (kg/s)	Bottom Ash (kg/s)
1	Western Sub-Bituminous	0.2	15	20	4.31	51.67	5.81	1.94
2	Western Lignite	0.4	30	20	2.87	77.51	17.44	5.81
3	Refuse Coal	0.8	13	35	2.59	86.12	8.40	2.80
4	Eastern Bituminous	2.0	10	10	5.75	38.75	2.91	0.97
5	Eastern Bituminous	5.0	8	10	6.23	35.77	2.15	0.72

TABLE 34 WATER USE IN GENERIC CLOSED-LOOP BOTTOM ASH SYSTEM

Coal Type	Bottom Ash Generated (kg/s)	Sluice Water Required (L/s)	Evaporation in Quenching (L/s)	Ash Occlusion in Hydrobin System (L/s)	Ash Occlusion in Lagoon System (L/s)	Total Water loss			
						Hydrobin System (L/s)	Lagoon System (L/s)	Hydrobin System (L/min/MW)	Lagoon System (L/min/MW)
1	1.94	192	1.26	1.05	2.10	2.31	3.36	0.35	0.50
2	5.81	577	3.78	3.14	6.27	6.92	10.05	1.038	1.508
3	2.80	278	1.82	1.51	3.02	3.33	4.84	0.50	0.73
4	0.97	96	0.63	0.52	1.05	1.15	1.68	0.17	0.25
5	0.72	71	0.47	0.39	0.78	0.86	1.25	0.13	0.19

scale. The mass balance in the generic ash handling system, shown in Figure 41, can be defined by the equation:

$$C_1 = \frac{C_7Q_7 + C_8Q_8}{Q_1}$$

In this equation it is assumed that there is no loss of chemical constituents into the furnace ($C_2 = O$), and that precipitation balances evaporation from the ash settling equipment ($Q_6C_6 = Q_5C_5$).

Based on the mass balance of the generic recirculating system, only a small change occurs in the concentration of scale-forming minerals due to a two-percent make-up.

Based on the five coal types, the dilution of the make-up water reduces the concentration of the ionic species of concern by about 13 mg/L. Thus, if the increase in concentration of the given ionic species due to contact with the bottom ash is greater than approximately 13 mg/L, scaling will ultimately occur in the system. At most generating stations the increase in the concentration of a given ionic species will likely exceed this value, which suggests that scaling should be commonplace. However, this and other bottom ash transport system models do not consider the removal mechanisms for scale-forming minerals.

In all but one station studied as case histories, no scaling was evident in the recirculation systems. This occurs, as previously discussed, because of:

- abrasion of scale on the ash slurry side of the system where precipitation occurs first;
- preferential precipitation of scaling minerals on suspended solids in the ash slurry on the discharge side;
- removal of calcium due to the dissolution of atmospheric carbon dioxide;
- preferential precipitation on the return side of the recycle system;
- dilution of the sluice water by the addition of make-up water.

These factors act to remove scale-forming minerals from the sluice water.

In only one situation in the case histories studied was scale present in the recirculating bottom ash transport system. In this particular case, several factors contributed to the formation of scale:

- Western Canadian coal was being burned.

- Make-up water had a high calcium concentration and pH.
- Ash sluice velocities in the ash discharge lines from the bottom ash hopper to the hydrobin were low.

In such cases, three options exist to control the problems associated with scale formation. These include:

- use of scale inhibitors,
- pH reduction by acidification,
- calcium removal by softening.

The use of scale inhibitors is a possible treatment option. Scale inhibitors permit waters to be used which would form scale if the chemical additive was not present. When the ability of the scale inhibitor to prevent scale formation is exceeded, however, a much greater scale problem would exist since the water has been artificially maintained. The use of scale inhibitors would only prolong the time until the water quality would degrade such that a scaling problem would reoccur. The volumes of water that would require treatment and the cost of chemicals make this approach economically unattractive. It is unlikely that any benefit can be gained using this approach, particularly in waters where the Langelier Index exceeds +3 to +4.

The second alternative to reduce existing scaling problems is by pH reduction by acidification to prevent the formation of calcium carbonate scale. Based on the Langelier Index, the most significant reduction in scaling potential can be achieved by reducing the pH. This method would be the most economically attractive.

The addition of an acidic waste stream as a make-up water would reduce the total wastewater discharge from a station and would help reduce the presence of calcium carbonate scale. Coal pile runoff, which can be highly acidic, could be used for this purpose. However, the addition of other chemical constituents from the coal pile runoff to the bottom ash sluice water must also be considered.

Another alternative is to acidify using sulphuric acid. The addition of the acid would lower the pH and reduce the formation of $CaCO_3$ scale. Ideally, the sluice water return line would be acidified to protect this side of the ash transport system. Pilot plant work would be necessary to determine the quantities of acid required for adequate protection and the best location for the acidification.

The third option for the reduction of a scaling problem would be the removal of calcium from the recirculated water. A variety of techniques are available to

accomplish this; however, lime-soda softening has been demonstrated technically and is most economically attractive.

The mechanical removal of scale (pigging) has been suggested as a possible fourth option. This technique is likely impractical due to the nature of the scale, the diameter of recirculation lines and their length.

In the one station visited where a scaling problem existed, the $CaCO_3$ scaling was limited to the ash sluice side of the system. The accumulated scale is removed from the lines by acid washes with hydrochloric and sulphuric acid. This is performed every other year during routine shutdown of the units.

7.1.3 Mechanical Problems. Several mechanical problems identified in this study could affect either a once-through or recirculating bottom ash systems. These may be more severe in recirculating systems due to the additional pumping and recirculation equipment.

In areas of Canada where extreme winter conditions exist, there is a possibility that recycle lines and hydrobins could freeze and cause equipment failures. This is particularly important when ash is sluiced periodically and where sluice water is stationary in the lines. This type of problem has been encountered at several of the case history stations. Remedial action includes insulating or heat tracing equipment in the system and designing the sluice lines to be self-draining.

Mechanical abrasion of sluice lines and pumps is a common concern in bottom ash transport systems. This problem will occur whether the system is a recirculating system or not. Pump wear problems can occur in a recirculation system if retention time in the ash settling equipment is inadequate. Ash particles which do not settle can be returned with the bottom ash sluice water and can damage the recycle water pumps. This problem can be eliminated by adequate retention time in the ash settling equipment.

At one of the stations visited, concern was expressed about corrosion of the sluice water pumps because the recirculated bottom ash sluice water was slightly corrosive. In this station, the recycled water is monitored and the pH is adjusted as necessary to protect the pump components from corrosion.

The most significant problems associated with the operation of a fully recirculating ash transport system where a lagoon is used to settle the ash is the gradual reduction in lagoon volume. Ash build up in the lagoon will continue to reduce the lagoon volume and hence the retention time. This will eventually reduce the quality of the recirculated water, which could affect the recycle water pumps. This problem is

particularly significant in recirculated combined ash lagoons. In these systems, lagoon management must provide for the periodic removal of settled ash from the lagoon or must ensure that new lagoon capacity is available when the recycled water from existing lagoons has significantly deteriorated due to decreasing settling time.

7.2 Conclusions and Recommendations

Based on this study the following conclusions can be made:

- There is a greater likelihood of the formation of calcium carbonate scale than calcium sulphate scale since calcium carbonate has a much lower solubility. The exception to this is in situations where a prolonged ice cover on the ash lagoon can affect the pH of the lagoon water and interfere with the carbon dioxide-carbonate equilibrium. In this case, all the carbonate can be removed from the water by precipitation with calcium. Excess calcium may form calcium sulphate scale. Based on current operating experience, there appear to be compensating factors which minimize the effects of prolonged ice cover.
- Since the rate of dissociation of chemical constituents from fly ash is greater than that from bottom ash, this is particularly important in the design of combined lagoon disposal systems. To maintain an acceptable recirculated water quality in this type of system, the dissociation and settling rates for the fly ash should be used to design the recirculation system. Combined lagoons should be considered only when no other ash disposal options are available because a greater potential for scale formation will exist.
- The loading of chemical species from other waste streams entering the recirculating system must be considered since these may include high concentrations of ionic species related to scale formation. The chemical constituents in natural make-up water must also be considered since raw water supplies may have a scaling potential.
- The severity of mechanical problems associated with the operation of recirculating bottom ash systems can be reduced by proper design. Problems caused by the freezing of sluice water lines can be greatly reduced as can reduced quality of overflow water from ash settling equipment. Erosion on the ash sluice side of the system can, however, only be partially reduced. Mechanical wear on the ash sluice side must be considered inherent in the system due to the physical properties of the bottom ash.

The feasibility of fully recirculated bottom ash transport systems can be stated as follows:

1. Hydraulically, zero discharge can be achieved in recirculating bottom ash transport systems unless other wastes or water sources exceed the one to two percent loss from the system. This can be achieved by careful management and balancing of water inputs and losses to the bottom ash transport system.
2. The severity of scaling problems does not appear to be as great as is widely believed. Because removal mechanisms for scaling minerals are present in the ash transport water, fully recirculating (no discharge) bottom ash transport systems are technically feasible. Scale may form in the recirculation system in some cases. Methods such as sidestream lime-soda softening and acid cleaning are available to eliminate the accumulation of scale in these specific situations.

It has been shown that scaling in recirculating bottom ash transport systems is not as severe as would be predicted on a theoretical basis. A number of mechanisms which prevent scaling have been identified; however, it is not possible to specify on a site-specific basis which mechanisms are most responsible for the control of scale formation. It is, therefore, recommended that further studies be conducted to determine the relative contribution of each under various operating conditions.

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APPENDIX
ECONOMIC ASSESSMENT OF MECHANICAL ASH REMOVAL SYSTEMS

APPENDIX - ECONOMIC ASSESSMENT OF MECHANICAL ASH REMOVAL SYSTEMS

Mechanical ash systems have been promoted on the basis that they can be easily repaired and maintained while in operation, and on their lower costs and reduced water usage. Four cost factors are considered: purchase price, installation, operation and maintenance. The following economic assessment is based on work by the Allen, Sherman, Hoff Company*:

1) Purchase - This system appears to have a lower capital equipment cost compared to conventional systems since no dewatering bins, recirculation tanks or high pressure pumps are required. Because the drag bar system is lower than a conventional system, the boiler can be lowered, reducing the overall plant elevation. Depending on the inventory of spare parts, heat exchanger and water clarification equipment and water circulation components, the mechanical system may be as expensive as a hydraulic system. This does not include consideration of the return lines and pumps used in a recycling hydraulic system. The actual costs of the equipment would be dependent on the manufacturer. One vendor cites the cost comparison in Table A.1 for a 400-MW boiler burning 6.4 MJ/kg coal with an ash content of 15 percent.

2) Installation - The installation cost of a mechanical system should be comparably less because more of the equipment is mechanical components and because of lower fabrication costs. While hydraulic systems have a large amount of piping, pumps, valves, fittings and more bins for water storage which are assembled in the field, mechanical systems are shop fabricated with on-site erection. In place of the usual conveying pipe, conveyor belts are required which are expensive to install.

3) Maintenance - These costs are difficult to predict; however, experience has shown that mechanical systems require more maintenance. This is due to the number of moving parts and its continuous operation. Likely, more manpower would be required for the system's operation. Wear is held to a minimum by the slow speed (0.03 to 0.04 m/s) of the chain. The equipment is accessible which should help reduce maintenance costs. In some European installations, a redundant conveyor system is used in the event of a failure of the first system.

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* Gretz, C.R., "Preliminary Study of Mechanical Bottom Ash Handling Systems for U.S. Applications", the Allen-Sherman-Hoff Company, Malvern, PA, May 1979.

TABLE A.1 COST COMPARISON OF BOTTOM ASH HANDLING SYSTEMS

System Type	Capital Costs*	Power Requirements (kW)			Circulating Water Flow (L/s)	
		Installed	Normal	Maximum	Continuous	Maximum
Hydraulic	1 425 000**	865.01	126.77	443.69	25.24 to 126.20	287.11
Mechanical	828 000	58.16	22.37	41.01	8.20	8.20

* Estimate, exclusive of erection costs, in 1978 U.S. dollars.
** Does not include return water piping and fittings.

For this comparison both the installation and maintenance costs will be assumed to be equal as there is as yet no operating experience in North America.

4) Operation - Since mechanical systems do not require high pressure pumps, the installed and operating horsepower are reduced. This system must operate continuously with only brief shutdowns for maintenance. The mechanical systems have very limited controls which minimizes operator involvement. A typical hydraulic system has numerous components which must be operated in the proper sequence. Based on a present value of $422/kWh for energy use over the life of the plant and $637/installed kW capacity cost, Table A.2 details the equipment and its costs for a hydraulic hydrobin bottom ash removal system for a 600-MW generating station, and Table A.3 shows the equipment necessary and its costs for a comparative mechanical bottom ash transport system.

TABLE A.2 COST DETAILS OF A HYDRAULIC SYSTEM FOR BOTTOM ASH CONVEYANCE

a) Ash hopper - two Sections, 212 m^3 two 1 m x 1 m Gates with 1-m Grinders	$ 375 000
b) Slurry Pumps - 2 Warman 10/8 FM for 88 L/s @ 30.5 m	40 000
c) Piping - 91 m, 203 mm w/Fittings and Valves	25 000
d) Recirculation Tanks - two 7.6-m Hydrobins, 283 m^3 one 15-m Settling Tank, one 17-m Surge Tank, 680 m^3	675 000
e) Recirculating Pumps - two - L.P. for 25 L/s @ 30.5 m, two Flush Pumps for 139 L/s @ 98 m	100 000
f) Controls	35 000
	$1 250 000

The power consumption of a hydraulic ash transport system as shown in Table A.4 can be compared to the power requirements of an equivalent-sized mechanical transport system shown in Table A.5.

TABLE A.3 COST DETAILS OF A MECHANICAL SYSTEM BOTTOM ASH CONVEYANCE

a)	Transition Chute - Continuous Opening Refractory Lines, Seal Trough, etc.				$ 300 000
b)	Drag Flight Conveyor - 61 m long w/1.5 m x 1.5 m Casing				300 000
	Itemized as follows:				
	1) Casing			$200 000	
	2) Chain - 122 m			15 000	
	3) Sprockets	2 @	$1 350	2 700	
	4) Idlers	14 @	875	12 500	
	5) Bearings	16 @	450	7 200	
	6) Flight Bars	266 @	100	26 600	
	7) Wear Pads	532 @	10	5 320	
	8) Shafts	8 @	275	2 200	
	9) 30 kW Vari-Speed			18 000	
c)	Discharge Chute @ end				10 000
d)	Belt Conveyor - 91 m				275 000
e)	Storage Bin - 283 m^3				125 000
f)	Lamella - one Model 2500/55 Complete w/Poly Dose, Flash Tank, etc.				166 000
g)	Heat Exchangers - two for 69 L/s - 10°C Drop				36 000
h)	Sludge Pumps - two for 7 L/s @ 12 m TPH				8 000
i)	Surge Tank - one 12-m Diam. w/283 m^3				115 000
j)	Recirculating Pumps - two - L.P. for 25 L/s @ 30.5 m 2 Flush Pumps for 44 L/s @ 98 m TDH				80 000
k)	Controls				35 000
					$1 450 000

TABLE A.4 POWER REQUIREMENTS OF A HYDRAULIC BOTTOM ASH TRANSPORT SYSTEM

Item	BkW	Time per Shift (min)	kWh/d	Installed kW
Conventional System with Jet Pumps				
H. P. Sluice Pumps	459	90	2 064	522
L.P. Pumps	15	480	358	37
Flush Pumps	78	40	157	224
Sludge Pumps	5.6	480	134	30
Sump Pumps	8.9	480 + 60	242	34
			2 995 kWh	847 kW
			x 422	x 637
			$1 250 000	$540 000
Conventional System with Slurry Pumps				
Slurry Pumps	48	90	218	112
L.P. Pumps	15	480	358	37
Flush Pumps	186	90	839	447
Sludge Pumps	5.6	480	134	30
Ash Hopper Sump Pumps	8.9	480 + 60	242	34
			1 791 kWh	660 kW
			x 422	x 637
			$ 756 000	$420 000

TABLE A.5 POWER REQUIREMENTS OF A MECHANICAL BOTTOM ASH TRANSPORT SYSTEM

Item	BkW	Time per Shift (min)	kWh/d	Installed kW
Mechanical System				
Drag Conveyor	7.5	480	179	30
L.P. Pumps	15	480	358	37
Flush Pumps	112	40	157	224
Lamella Sludge Pumps	1.5	480	36	4.5
Conveyor Sump Pumps	8.9	480 + 60	233	34
			963	329.5
			x 422	x 637
			$406 000	$210 000

Summary of Cost Comparison

Based on this comparison of costs for a mechanical and a hydraulic system with hydrobins, a summary of cost data for these systems is presented in Table A.6. Slurry pumps are used instead of the more expensive jet pumps for costing of the hydraulic system.

TABLE A.6 COST COMPARISON OF CONVENTIONAL AND MECHANICAL ASH TRANSPORT SYSTEMS

Item		Mechanical	Conventional with with Slurry Pumps
1.	Purchase*	U.S. $1 450 000	U.S. $1 250 000
2.	Installation	800 000	800 000
3.	Maintenance	-	-
4.	Operation	616 000	1 716 000
	TOTAL	$2 866 000	$3 226 000

Difference = $360 000 or 11% in favour of a mechanical system. If present day worth were applied, the advantage would decrease.

* Lower boiler arrangement ignored.

The mechanical bottom ash transport system was shown to have a slightly higher purchase price, however, the operating costs were significantly lower than a comparatively-sized conventional system. The cost of a complete mechanical transport system can be estimated using a factor of $3.50/kW for the generating station nominal capacity.

From this evaluation, the following operating cost advantage for a mechanical system can be assigned:

1. Mechanical vs Jet Pump:

Energy	=	$1 250 000	-	$ 406 000	=	$ 844 000	
Capability	=	$ 540 000	-	$ 210 000	=	$ 330 000	
				Total	=	$1 174 000	Advantage

2. Mechanical vs Slurry Pump:

Energy	=	$ 756 000	-	$ 406 000	=	$ 350 000	
Capability	=	$ 420 000	-	$ 210 000	=	$ 210 000	
				Total	=	$ 560 000	Advantage

This system can also be integrated with a pyrite system and economizer hopper ash removal systems. These discharges can be routed to be deposited in the water filled trough for removal by the submerged drag chain. These systems are not greatly affected by the use of mechanical bottom ash removal system.

There appear to be strong incentives for this system. The water use and hence its treatment and related costs are reduced. There is a considerable saving in power required for its routine operation. Major disincentives are the possibility of the continuous high maintenance of the system and inexperience with this system in North America.

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